# PRE DESIGN COST ESTIMATES FOR TREATMENT PLANTS : AN APPROACH

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# CERTIFICATE

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# NOMENCLATURE

| | |
|---|---|
| BI | Basic Item |
| BLS | Bureau of Labour Statistics |
| BOD | Biochemical Oxygen Demand |
| B/W | Brick Work |
| CBI | Cost of Basic Item |
| CC | Cost of Component |
| CCI | Cost of Composite Item |
| CI | Composite Item |
| C/S | Cross Section |
| CUO | Cost of Unit Operation |
| CUP | Cost of Unit Process |
| $C^r$ | Cost at rth Level |
| ENR | Engineering News Records |
| EUC | End User Cost |
| $f^r$ | Fraction of sum of the Costs of rth Level Subsystems to Make a (r+1)th Level Subsystem which Accounts for Making an Orderly Set of Subsystems of Level r |
| GA | General Alignment |
| HP | Horse Power |
| HRT | Hydraulic Retention Time |
| $I^r(J_r)$ | Index for a $J_r$ Subsystem at rth Level |
| MGD | Million Gallons per Day |
| MLD | Million Litres per Day |
| MT | Metric Tonne |
| MWSSB | Maharashtra Water Supply and Sewerage Board |
| $N_r$ | Number of Subsystems at rth Level |
| O & M | Operation and Maintenance |

| | |
|---|---|
| PCC | Plain Cement Concrete |
| PHS | Public Health Service |
| PL | Plastering |
| $Q^{Jr}(J_{r-1})$ | Quantity of $J_{r-1}$ th Subsystem of Level r-1 Required to Make $J^r$th Subsystem of Level r |
| $R^r(J_r)$ | Unit Cost (Rate) of Subsystem $J_r$ at Level r |
| RCC | Reinforced Cement Concrete |
| SL | Skilled Labour |
| STP | Sewage Treatment Plant |
| TCC | Total Capital Cost |
| T & P | Tools and Plants |
| TOMC | Total Operation and Maintenance Cost |
| TPC | Total Plant Cost |
| UHDL | Unskilled Heavy Duty Labour |
| ULDL | Unskilled Light Duty Labour |
| UO | Unit Operation |
| UP | Unit Process |
| USEPA | United States Environmental Protection Agency |
| WP | Waterproofing |

## ABSTRACT

Predesign estimates of water and wastewater treatment plant costs are necessary for budgetary provisions as well as selection of effective and economical treatment chain. The work presented in this thesis is an attempt to suggest an approach for rapid estimation of predesign treatment plant costs. A conceptual model is presented for visualizing breakup of treatment plant cost which considers a branched structure of subsystems of various levels contributing to the overall cost with lowest level of subsystems (units) as basic items (parts) and highest level of subsystems as unit processes. A mathematical formulation based on this conceptual model is derived to obtain capital and operation and maintenance (O & M) cost of the overall plant. Cost data were synthesised through rate analysis and quantity survey using principles and practices followed by engineers. Nonlinear regression analysis is employed to obtain best fit curve(s)/ function(s) in terms of the identified capacity parameter(s) of a unit operation for quantities of items involved and the cost. Six selected unit operations, namely screen chamber, grit chamber, aeration tank of activated sludge process, secondary clarifier, anaerobic digester and sludge drying beds are considered. Emphasis has been given on civil works cost. Mechanical equipment cost curve(s) are presented for aeration tank and secondary clarifier only. In order to ensure universal adoptability and continued usability of the results obtained from cost curve(s)/function(s), application of indices at various levels which appropriately reflect the variation in economic factors over a time and geographic scale from reference conditions is suggested. These indices are formulated in such a way that they reflect the changes in the unit costs (rates) of subsystems/units (basic items) on the changes in the unit costs of higher level subsystems such as composite items, components, unit operation, etc.

## KEY WORDS

Predesign estimates, cost breakup, cost curves, cost functions, cost indices, capacity parameter(s), unit operation, unit process, treatment plant, water treatment, wastewater treatment.

# 1. INTRODUCTION

It is generally agreed that economic appraisal of any project is a fundamental part of engineering analysis and is in fact so closely associated that from a practical point of view, analysis without economic considerations is meaningless. This concept was expressed in an unusually lucid manner by Dunn (1939) as follows.

> "The essential importance of the work of an engineer lies in economic involvement of his work. It is in this hot crucible of the economic test that all an engineer does must be tried ...... and it is because the engineer's art deals with dollars and economic relations that he is bound into great business structure of the society."

In the development of a process of water/wastewater treatment and the design of a treatment plant, frequent economic appraisals are made in order to eliminate from active study or detailed engineering, those developments in which the return on investment is not justifiable and to concentrate engineering efforts into channels leading to the most attractive end results (Chilton, 1949). These economic appraisals obviously must be made without the benefit of firm estimates based on detailed design. Some indication of the cost of constructing the commercial plant is required, so an estimate is prepared by an engineer with previous estimating experience and a reference file of cost data. This type of estimate while varying widely in the amount of time spent in developing the necessary data and in the dependability of the results, may be broadly termed as a "Pre - Design" estimate.

With increasing concern for protecting precious natural resources and building pressures of pollutants load on the environment all over the world, it will be imperative for all cities with substantial population (say one million and above) to seriously plan for water as well as wastewater treatment

facilities by the turn of this century. A rough estimate reveals that there would be about four hundred such cities in India alone. Considering present cost factors, this would mean that each of the cities will have to invest a capital of not less than Rs. 100 million taking conservative estimate of treatment cost as Rs. 1000 per cum per day. Considering the huge expenditures involved, it is necessary that appropriate budgetary provisions are made at the planning stage. Since these provisions have to be made without detailed design and that too by engineers who are not specialised in the field, it is necessary that a simple and rapid technique for treatment plant cost estimation is available.

More dependable and methodical way to obtain these predesign estimates rapidly is use of cost curves or cost functions. Cost function is defined as any relationship that provides estimate of cost in terms of the values of more basic variables such as process or physical parameters.

Many approaches have been tried in the development of graphical or mathematical expression for cost estimation. Traditionally, cost directly in dollars or unit cost in dollars per flow unit (MGD) has been used as dependant variable. Many parameters such as flow, influent quality, efficiency, population equivalent removed etc. have been used as independent variable, one or more at a time. None of these serve the purpose individually as all of them influence the plant cost simultaneously. Even if more than one of these are used together they can not overcome the inherent drawback that they do not reflect choice of components of treatment chain and its effect on the cost.

Construction cost and operating cost have been separated since beginning. Separate equation for each type of secondary treatment was the next development, though equations derived are for cost of plant as a whole and not for unit processes (e.g. primary, secondary, etc.). This approach enables user to compare between the two plants for same conditions using same secondary process, but does not allow to compare between two plants for same

conditions using same unit process but different chain of unit operations in an unit process. This warrants separate curve for each of the components or unit operations.

To increase the flexibility in use of cost curves, separate curve should be developed for each unit operation and the plant cost should be obtained by addition of unit process costs. Moreover instead of using process parameters as independent variables, physical parameters should be used as they are directly related to the cost. This will give choice of selection of chain of unit operations as well as choice to select geometric configuration of unit operation as per site requirement. The present investigation is an attempt in this direction.

Once cost curves are developed for particular reference conditions (i.e. for selected geographical location and year), method is required to modify cost curve results with variation in time and geographic location. Initially Engineering News Record Construction Cost index was used, but the skill required in process plant construction and the heavy duty works, necessitated separate index for sewage treatment works. However, even this index fails to appropriately reflect changes in the plant cost due to changes in the economic factors affecting the cost as rate of one item (e.g. steel) will not change in same manner as that of the other (e.g. cement).

Hence, separate index should be developed to modify results obtained from curves/functions for each unit operation, which in turn should be a composite of indices for cost components of that unit operation. This concept has been adopted in present research in formulation of logistic for using cost curves/functions for conditions where economic factors are considerably different than those for which these curves/functions are developed.

# 2. LITERATURE SURVEY

## 2.1 General

Self adjusting mechanism of Demand - Supply and market price is not applicable to engineering projects. Implicit cost being an important constituent of the cost, there may be considerable difference in cost and value of the project. Cost of the same project at same time may be different for client, consultant and contractor. It also depends on whether the client is a government body or a private organisation. Stage of the project is also one of the aspects. Project cost will be one at planning stage and the other after detailed design and engineering and yet another when the project is completed. Though many factors govern the difference between estimated cost after detailed design and actual cost at completion, it is the responsibility of an engineer making predesign estimates that the difference between predesign and postdesign estimates is within reasonable limits. It is possible to master the art by experience but it is a very lengthy process. Hence, it is desired to have a technique which will enable even a beginner to make reasonable predesign estimates.

## 2.2 Historical Development

Necessity of developing a technique for rapid estimation of water and wastewater treatment cost was felt by engineers several decades ago. However, attempt to develope such techniques in a systematic way appears to have been initiated by engineers in United States in late 1940's. Their work introduced the concept of cost curves or cost functions for water and wastewater treatment plants. The treatment costs were broadly divided into capital and operation and maintenance costs. Cost functions for wastewater treatment were first reported by Velz (1948) and similar approach for chemical plants was reported by Chilton (1949). Rowan *et al.* (1961) exclusively studied operation and maintenance costs by obtaining information on about 320 plants through detailed questionnaries sent to various plant operators. Logan *et al.*

(1962) reported results for both capital as well as O & M cost based on data collected on about 60 plants through field visits. These two publications are considered as milestones in cost curve development. Smith (1968) used averages of the data collected by six previous publications (Logan *et al.*, 1962; Public Health Service Publication, 1964; Velz, 1948; Diachishin, 1957; Rowan *et al.*, 1961; and Swanson, 1966) and developed separate cost functions for various unit processes. One of the well planned and relatively recent study on the development of curves for capital costs was conducted by Shah and Reid (1970) based on the information collected from 563 plants all over United States. They statistically checked validity of equations and recognised dependability of cost on more than one parameter at a time. A similar exhaustive work based on data collected from over 1500 plants is reported by Michel (1969) for O & M costs. The most comprehensive work on mechanical equipment cost in treatment plant was sponsored by United States Environmental Protection Agency (Blecker and Cadman, 1973). Until late seventies no significant efforts were made to develop curves for water treatment . Clark (1982) reported in detail studies conducted on cost curve development for water treatment. This work was a part of USEPA sponsored project.

Tihansky (1974) reported state-of-the-art of water pollution cost functions which covers wide spectrum of the studies carried out using different approaches. Under Indian conditions the only reported work appears to be by Alagarsamy and Gopalkrishnan (1987) for water treatment cost. In this they used data from six plants varying from 0.3 upto 20 MLD in capacity. Table 1 shows literature available at a glance compiled on the basis of approaches used by various workers.

## 2.3 Treatment Plant Cost Partitioning

Since at the beginning of any project in general and wastewater treatment plant in particular, items contributing to cost are many. Land cost, legal fees, administrative cost, etc. are the costs normally incurred before commencement of execution

Table 1 : Literature Survey at a Glance

| | |
|---|---|
| Mode of Data Collection/ Generation | 1) Questionnaries : Rowan *et al.*, 1961; Michel, 1969; Shah and Reid, 1970; Clark *et al.*, 1979<br>2) Field Visits : Logan *et al.*,1962<br>3) Data Generation : Logan *et al.*, 1962 |
| Type of Cost | 1) Total : Velz, 1948; Diachishin, 1957; Assenzo, 1963<br>2) Capital : Logan *et al.*, 1962; Shah and Reid, 1970; Clark *et al.*, 1979; Rowan *et al.*, 1960<br>3) O & M : Rowan *et al.*, 1961; Michel, 1969 |
| Cost Breakup | 1) Primary/Secondary : Velz, 1948; Diachishin, 1957<br>2) Unit Process : Logan *et al.*, 1962; Rowan *et al.*, 1961; Assenzo, 1963; Shah and Reid, 1970<br>3) Unit operation : Smith, 1968; Clark *et al.*, 1979 |
| Function Form | 1) Power : Velz, 1948; Logan *et al.*, 1962; Rowan *et al.*, 1961<br>2) Exponential : Assenzo, 1963; Shah and Reid, 1970<br>3) Polynomial : Clark *et al.*, 1979 |
| Independent Variable Used | 1) Flow : Velz, 1948; Diachishin, 1957; Logan *et al.*, 1962; Shah and Reid, 1970<br>2) Efficiency : Rowan *et al.*, 1960<br>3) Population Equivalent Removed : Assenzo, 1963; Shah and Reid, 1970<br>4) Process Parameter : Smith, 1968; Stenstrom and Andrews, 1980 |
| Index/Indices Used | 1) ENR - C : Logan *et al.*, 1962; Shah and Reid, 1970<br>2) ENR - STP : Shah and Reid, 1970<br>3) PHS - STP : Smith, 1968<br>4) BLS Indices : Smith, 1968; Clark *et al.*, 1979 |

ENR-C: Engineering News Record Construction Cost Index; ENR-STP: Engineering News Record Sewage Treatment Plant Index; PHS-STP: Public Health Service Sewage Treatment Plant Index; BLS: Bureau of Labour Statistics.

of the project. Historically these costs have not been considered for the curve development though Clark (1982) suggested to add a certain percentage of total project cost to account for them. Logan *et al.* (1962) considered administrative cost and legal fees

for treatment plants and divided these costs equally among all the unit operations in the plants.

Capital cost is a cost incurred after design and before commissioning of the plant. It includes cost of civil, electrical, mechanical, and piping work. Alagarsamy and Gopalkrishnan, (1987) gave separate curves for each of these types, while many other studies (e.g. Logan *et al*, 1962) included only cost of civil work and mechanical equipment in capital cost and added fixed percentage of these for electrical and piping work. Cost of civil work is made of cost of various items of construction (e.g. RCC, PCC, Steel, etc.) while that of mechanical equipment is made up of ex-works price of equipment, transportation cost, etc. Electrical work cost is made up of cost of transformer, cost of cabling, cost of site lighting, etc., and piping cost is made up of cost of pipe material, laying, lowering, support structure, etc. All these costs can finally be broken up into material cost, labour cost, energy cost etc.

Logan *et al.* (1962) divided plant cost in terms of preliminary, primary, and secondary treatment and cost of sludge handling and pumping. They gave separate equations of each of these for total capital cost. Smith (1968) further divided unit processes into unit operations. He gave separate curve for biological reactor and settling tank in secondary treatment, separate curve for digester and sludge drying beds in sludge handling, etc. Clark (1982) followed this approach for water treatment plants. This shows that when many divisions of treatment plant costs are considered, a big matrix is formed. Each element of this matrix can be represented by a separate equation for cost component contributing to capital cost of a treatment plant.

Cost incurred after comissioning of a plant is operation and maintenance cost. Rowan *et al.*, (1961) gave cost equations for O & M cost based on secondary treatment used. O & M cost can also be divided into cost of labour, cost of energy, cost of materials and chemicals, etc. This type of division was considered by USEPA for preparing report on O & M cost of water treatment plants (USEPA, 1978).

Point to be noted here is that every element of the above mentioned matrix should have separate index, to be applied to reference cost values, which when interwoven following certain logistic should ultimately give index for appropriately reflecting changes in the overall cost of plant from the standard or reference conditions for which the cost curves or functions are developed.

**2.4 Approaches for Rapid Estimation of Treatment Plant Costs**

Matrix of cost components described in previous section has not been considered entirely in any one of the studies reported. However, a major portion has been studied by various investigators separately under the projects sponsored by USEPA. Irrespective of the components or a set of components for which a cost curve is being developed, the approaches followed can be broadly divided in three categories based on the factor(s) which predominantly control the cost. These factors in general can be called as independent variables (IV's) for the cost curve or the function and may include one or more of the following.

Flow: All early workers (Velz, 1948; Diachishin, 1957; Rowan *et al.*, 1961) used flow as the only independent variable. The major drawback of this approach is that plants with same flow and different efficiencies will have same cost which is unlikely.

Efficiency or related parameter: Cost curve development has been done traditionally for treatment of municipal wastewaters because of its significance and ease in data collection. Hence, it was generally assumed that the influent BOD will be around 250 to 300 mg/l and the treatment will be to meet prevailing standards. This being the reason, not many workers considered efficiency as important variable affecting the plant cost considerably. Assenzo (1963) used effluent BOD and efficiency as independent variable for the cost curve development. Logan *et al.* (1962) used population equivalent removed (which include flow and efficiency both) and effluent BOD as independent variables along with flow.

Demerit of these two approaches is that they do not provide flexibility in functional design of the plant.

Process parameters: With trend to give separate cost function for each of the unit processes and in turn for each of the unit operations, flow or efficiency of plant as a whole were no more relevant parameters. Smith (1968) suggested to use process parameter such as surface area of clarifier, HRT for aeration basin, etc. Stenstrom and Andrews (1980) gave cost of plant as related to solids retention time. This approach, though provides user to select chain of unit operations, does not allow selection of geometric factors which depend upon site conditions and may affect considerably the cost of piping, mechanical equipment, etc. Use of physical parameters as independent variable having direct bearing on cost could be the solution to this problem.

## 2.5 Cost Data Collection/Synthesis

Irrespective of which approach is followed for analysis of cost data it is interesting to see what are the ways in which this cost data is collected or generated.

Collection of cost data can be done from many sources like contractor, consultant, client, public health authorities, etc. Contractor will never disclose actual expenditures incurred on any job. Red tape may interfere in data collection from government bodies. Also clients normally have total expenditure figures but no breakup. Hence, consulting firm is the best source having all required information. Traditionally this source has been tapped. Rowen *et al.*,(1961); Shah and Ried (1970); Michel (1969) used questionnaries for data collection while Logan *et al.*, (1962) preferred to visit treatment plants. Visiting plants put limitations on number of data points, but by sending questionaries one can not be sure of good response.

Another method used by Logan *et al.*,(1962) was to design standard treatment plants based on idealised conditions for predetermined flow, efficiency, influent BOD, geographic location and time. They designed 34 plants with 200 mg/l as influent BOD

and the flow of 0.25, 0.5, 1.0, 5.0, and 10.0 MGD with predetermined chain of treatment units. Operating costs for these "Standard Plants" were based on field data analysed and applied to hypothetical plants.

Both these methods do not give any choice in selection of unit operations. To overcome this limitation the combination of these two methods is suitable. In this third approach data collection or data generation is done without any consideration to flow or any of the process parameters. Data is collected based on physical specifications of unit operation under consideration. It is very difficult to obtain such information directly from the field. Hence, the best way is to go through the process of quantity survey for each item contributing to the cost for suitably selected specifications within the feasible range. Quantity survey and the prevailing rates can lead to the cost of unit operation as a whole. This approach has a distinct advantage of being universally acceptable as the variations in the individual cost factors can be appropriately incorporated to account for differences in reference conditions for which cost curves/functions are developed from that of the actual conditions where these curves/functions are applied. This approach is reported for operation and maintenance cost (USEPA, 1978). However, no information is available using this approach for capital cost of the treatment plants.

## 2.6 Methods of Expressing Treatment Plant Cost Data

Two distinct modes, namely graphical and mathematical are adopted for rapid estimation of treatment plant costs. Graphical presentation is easier in terms of visualization and application but suffers from the limitation that not many independent variables can be considered simultaneously. Several ways of graphical presentation has been reported in literature (Logan *et al.*, 1962; Smith 1968). Mathematically power (Velz, 1949; Rowan et al., 1961), exponential (Assenzo, 1963; Shah and Ried, 1970) or polynomial (Clark, 1982) expressions have been used. Mathematical expression allow the use of several independent variables and hence are more realistic.

## 2.7 Application of Cost Curve(s)/Function(s)

Continued usefulness of the cost curves/functions developed depends upon the ability of these to reflect changes on time and geographical scale in economic factors such as prices of the various components contributing to the overall cost of treatment plant.

Traditionally cost indices of various kinds have been used for such purposes. These include Engineering news record (ENR) building cost index, Public Health Services (PHS) sewage treatment cost index, ENR Construction cost index (Shah and Ried, 1970), labour cost indexes of Bureau of Labor Statistics (BLS) and BLS wholesale price index. ENR construction cost index was used by Logan *et al.*,(1962) and Shah and Ried, (1970). Smith (1968) used PHS sewage treatment cost index. It is to be recognised that treatment plants involve special type of construction and varying degree of mechanical and electrical equipment. As such application of any index without consideration to specificity of the plant is bound to give significant errors in estimation. None of these cost indices have features which can consider specificity of type of treatment plant.

Clark *et al.* (1979) in their USEPA sponsored project made an attempt, which to some extent accounts for specificity of type of treatment plant as a whole, to give a logical approach for arriving at a specific index value. They (Clark *et al.*, 1979) divided the capital cost into eight cost components for which index was available and assigned weightages to each of the components based on average percentage of the total cost contributed by the subtotal construction cost for each of the eight items. In this they used indices for various items such as concrete ingredients, still mill products, wages, etc. published by Bureau of Labour Statistics. This concept needs to be further developed so that a technique is available for computing site specific value of index for given treatment plant from the reference conditions for which cost curves/functions are reported.

## 2.8 Summary

Since costs of treatment plants are very much subjective, particularly before detailed design and execution, and more so depending upon the concerned party (end user), say owner, consultant, or contractor, it is necessary to give due consideration to end user while developing cost curves/functions. Keeping the end user in view, data collection or data generation should be done at corresponding level.

Traditionally planners in government bodies, municipalities, public health boards are referred to as end users. Hence, data collection was naturally confined to domestic waste. Thus most of the cost functions developed consider selected schemes or unit processes and operations giving very limited scope for their application. Eventhough some attempts are made to develope cost functions for a few unit operations considering process parameters as independent variables, these also have restricted applications due to limitation of non availability of appropriate logistic for converting costs obtained from curve developed for reference conditions to the actual conditions. Cost indices reported, have very limited domain of application since there is no mechanism to incorporate variation in rate of change of cost of basic elements contributing to the overall cost of a unit operation. These limitations can be eliminated if an approach from part to the whole is followed with appropriate logistic for allowing changes in the cost of each part (element) contributing to cost of the plant, from reference conditions to the actual conditions. This approach will no doubt involve consideration of the entire matrix of cost components but is likely to have much wider applicability on time and geographical scale.

The review presented, examines necessity, historical development, scope, methodologies and approaches adopted for formulation, collection and/or generation of data, modes of presentation of results and applications of the techniques available for rapid estimation of water and wastewater treatment plant costs, especially at the preliminary stage of design.

# 3. OBJECTIVES AND SCOPE

Review of literature presented in earlier section clearly indicates that the technique for rapid evaluation of treatment plant cost at the preliminary design stage which can allow for flexibility in functional design is not available. Results of previous studies can atmost be good enough with limited scope to compare the cost of two processes rather than giving predesign estimate because government official certifying economy of treatment process is considered as end user rather than the design engineer. Design engineer should be considered as end user because he has better idea of factors affecting cost and many a times he is the one giving advice to officials during cost appraisals.

Secondly earlier work is specific to particular geographic locations because of which results can not be used for other geographic locations. Further, no mechanism can be developed to transform results either on time or geographic scale because individual factors/components contributing to the cost of treatment plant vary at different rates and it is not known as to what is the relative weight of these cost factors.

Flexibility in functional design can be achieved by developing separate cost functions for each unit operation and the cost obtained from these curves then can be combined to give cost curves for higher order union. Also, relative weight of various cost factors contributing to the cost of a unit operation should be known for reference condition and there should be logistic available to determine relative weight of these cost factors under actual conditions.

The present study is planned and executed to evolve an approach for developing cost curves/functions considering these aspects. The ultimate objectives of the present studies are as follows.

1. Develope a technique for rapid estimation of water and

wastewater treatment plant cost adopting part to whole approach wherein treatment plants are considered as chain of unit processes which inturn are a selected sequence of unit operations, and each unit operation is an orderly set of specified components.

2. Develope a logical approach for obtaining cost estimates for variable conditions incorporating variations on time and geographical scale from reference conditions for which the estimates can be made rapidly from cost curves/functions.

The scope of the present study is restricted to the following aspects of the whole study required to achieve aforementioned objectives.

1. Formulation of overall methodology for development of cost functions in general and construction (civil works) cost in particular for various unit operations.

2. Development of construction (civil works) cost functions for six selected unit operations considering specific modifications of these unit operations.

3. Development of mechanical and electrical equipment cost function for two selected unit operations.

4. Formulation for obtaining cost of a unit operation under variable conditions from reference conditions for which cost curves/functions are formulated.

5. Test the validity of technique evolved for rapid estimation of unit operations' costs as in 1 to 4 above through comparison with the data obtained from field and suggest discrepancies/ corrective measures, if any.

# 4. FORMULATION

## 4.1 General

Treatment plant cost, like the cost of any other engineering project, very much depends on the stage at which it is determined (e.g. preliminary design stage, pre execution stage, pre commissioning stage, etc.) and the end user for whom it is determined (e.g. owner, consultant, contractor, etc.). It also depends upon the level (may be expressed in terms of annual turn over) and nature (e.g. government, semigovernment, public sector, private sector, etc.) of the end user. Variation of cost depending upon the stage of estimation is due to availability of details which enable finer estimates possible as we go from preliminary design stage to precommissioning stage. Since our interest lies in cost estimates at a given stage, the stage itself can not be a variable. Dependence of cost for a given stage on end user is due to variation in profits, overheads, expenditures, legal and administrative costs, etc. These not only vary depending upon level and nature of the end user but also vary from project to project. However, these can be conveniently considered as fixed percentage of the cost of physical resources involved for any specified end user. As such it would be logical to assume that the cost of physical resources is independent of the end user and can be considered as minimum common cost associated with a project for a given stage. The cost functions developed for the physical resources would be relatively insensitive to end user.

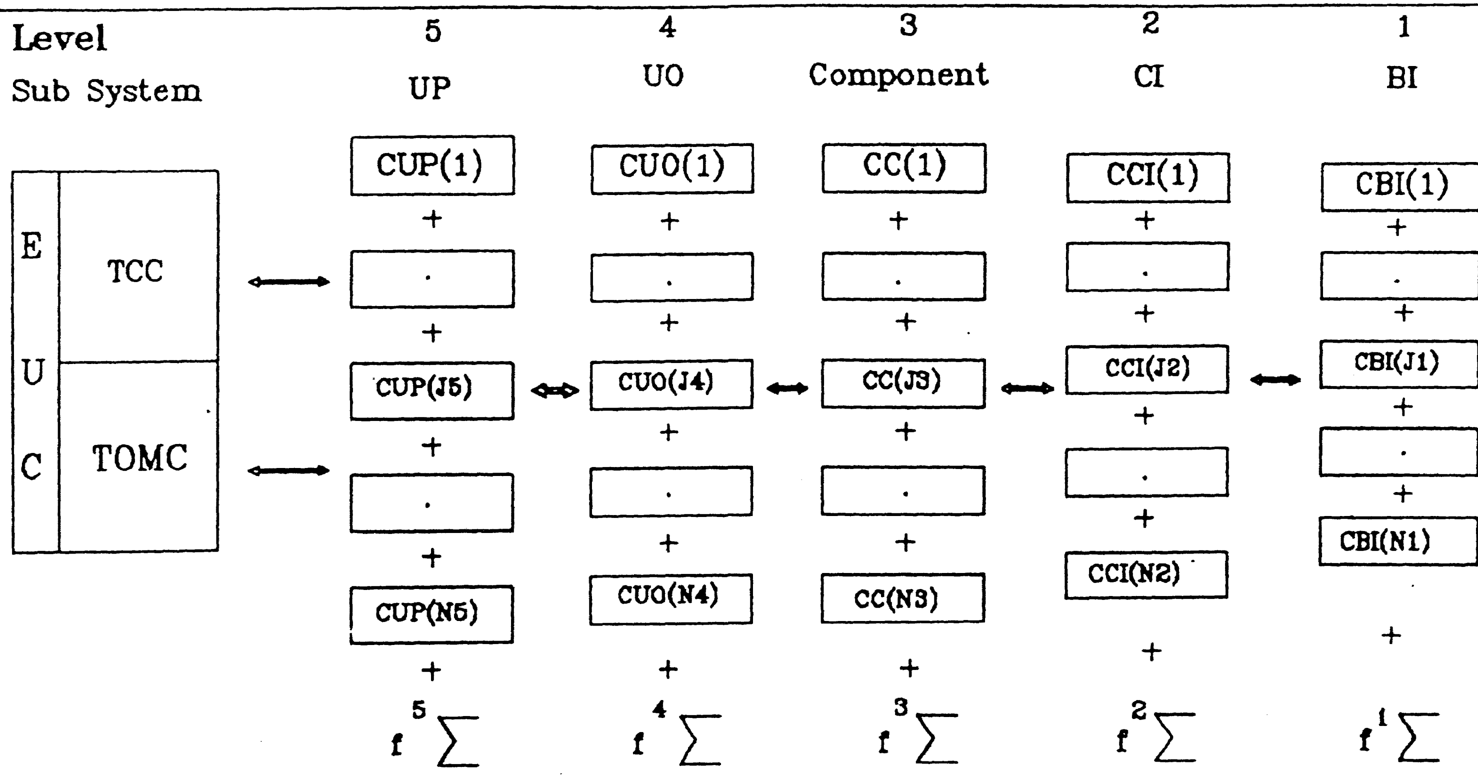
Thus, only the cost of physical resources involved is considered in formulating a rational approach to rapidly evaluate the cost of a treatment plant. It is assumed that the treatment plant cost can be readily estimated if the cost of a unit operation can be obtained directly either from a curve or a simple mathematical function in terms of the major capacity parameter(s) which influence the cost. Development of these cost curves\functions requires cost of unit operations for various values of the capacity parameter(s) under similar sets of site and economic factors. Therefore, cost curves/functions are strictly

applicable for a set of conditions, called as reference conditions, which reflect site and economic factors assumed in collecting cost data. Site conditions influence the cost of physical resources involved to a great extent and no general logic can be developed to account for variations in site factors. The only feasible solution appears to be to develope cost curves/functions for range of typical site conditions. However, changes in economic factors over time and geographical scale can be accounted through formulation of indices. These indices when applied to the results obtained from cost curves/functions available for reference conditions would appropriately reflect variation in economic factors.

**4.2 Cost Functions**

The cost functions are basically evolved from a fundamental unit of physical resources involved in modelling the whole system (treatment plant) from the investigation of parts (fundamental subsystems or units significantly contributing to the costs of a unit operation). This concept is represented schematically in Figure 1.

In general the whole system could be considered as an orderly set of several subsystems and each subsystem in turn could have several subsystems, and so on till we reach to a level where, from engineering analysis point of view, further sub divisions are not worth considering. Thus a system can be visualised as a structure with various levels of subsystems and a subsystem which does not need further subdivision can be called as a fundamental subsystem or a basic unit. In the present context, cost of each basic unit (level 1 sub system), can be called as level 1 cost. The level 2 costs are the costs of subsystems of level 2 which consist of level 1 subsystems or basic units. Likewise level 3 costs are the costs of level 3 subsystems which in turn consist of level 2 subsystems. And, in general r th level costs are the costs of that level of subsystems which consist of previous level (r - 1) of subsystems. Further, each level of cost can be divided into two parts. The first part, is associated with the cost




TPC = Total Plant Cost
TCC = Total Capital Cost
EUC = End User Cost
TOMC = Total O & M Cost
$N_1$ = Number of Basic Items
$N_2$ = Number of Composite Items
$N_3$ = Number of components

CUP = Cost of Unit Process
CUO = Cost of Unit Operation
CC = Cost of Component
CCI = Cost of Composite Item
CBI = Cost of Basic Item
$N_4$ = Number of Unit Operations
$N_5$ = Number of Unit Processes

Fig. 1. Schematic Representation of Treatment Plant Cost Breakup

contributed by several subsystems of previous levels, and the second part, which accounts for making a orderly set of previous level subsystems. The second part can be assumed as some fraction of the cost of the first part. Mathematically, the cost of any subsystem of r th level can be written as follows.

$$C^r = \sum_{J_{r-1}=1}^{N_{r-1}} C^{r-1}(J_{r-1}) + f^{r-1} \sum_{J_{r-1}=1}^{N_{r-1}} C^{r-1}(J_{r-1}) \qquad (1)$$

Here, $N_{r-1}$ is the number of subsystems of r-1 level involved in making a rth level subsystem, $C^{r-1}(J_{r-1})$ is the cost of a subsystem $(J_{r-1})$ of (r-1) level and $f^{r-1}$ is the fraction mentioned above.

Total plant cost (TPC) can be represented as an entity formed by summation of various types of costs added at different level, as follows.

$$TPC = \{ TCC + TOMC + EUC \} \qquad (2)$$

End user cost (EUC)includes legal fees, administrative charges, and profits and overheads at various levels. Summation of the costs of physical resources involved for obtaining total capital cost (TCC) or total O & M cost (TOMC) can be expressed as follows.

$$\begin{matrix} TCC \\ or \\ TOMC \end{matrix} = (1+f^5) \sum_{J_5=1}^{N_5} (1+f^4) \sum_{J_4=1}^{N_4} (1+f^3) \sum_{J_3=1}^{N_3} (1+f^2) \sum_{J_2=1}^{N_2} (1+f^1) \sum_{J_1=1}^{N_1} C^1(J_1) \qquad (3)$$

Here, TCC and TOMC are the total capital and operation and maintenance cost respectively, $N_1$ is the number of basic items involved in making a composite item, $N_2$ is the number of composite items involved in making a component, $N_3$ is the number of components involved in making a unit operation, $N_4$ is the number of unit operations involved in making a unit process, $N_5$ is the

number of unit processes involved in making treatment plant as a whole, $f^1$, $f^2$, $f^3$, $f^4$ and $f^5$ are the fractions of sum of the costs of basic items required to make a composite item, composite items to make a component, components to make a unit operation, unit operations to make a unit process and unit processes to make a treatment plant respectively.

To facilitate explanation of the meaning of the terms basic items, composite items, components, etc., an example list of these for a typical treatment plant is given in Table 2. A typical breakup of unit operation cost in terms of composite items can be represented as shown in Figure 2.

Table 2. Example List of Subsystems of Various Levels Considered in a Treatment Plant

| TERM | LIST |
|---|---|
| Unit Process | Primary Treatment, Secondary Treatment, etc. |
| Unit Operation | Screening, Aeration, Sedimentation, etc. |
| Component | Civil Work Cost, Mechanical Equip. Cost, etc. |
| Composite Item | RCC, PCC, Ex-Works price, Erection Cost, etc. |
| Basic Item | Cement, Sand, Steel for Reinforcement and Mechanical Equipment, Tools and Plants, etc. |

## 4.3 Indices

Cost functions are generally derived based on data collected/generated at reference conditions. Universal acceptability and continued usability of the cost functions can be ensured by introducing relevant cost indices at various levels which appropriately reflect the variation in economic factors over a time and geographic scale from reference conditions. These indices should be formulated in such a way that they reflect the changes in the unit costs (rates) of fundamental subsystems/units (basic items) on the changes in the unit costs of higher level subsystems (e.g. Composite items, components, unit operations, etc.).

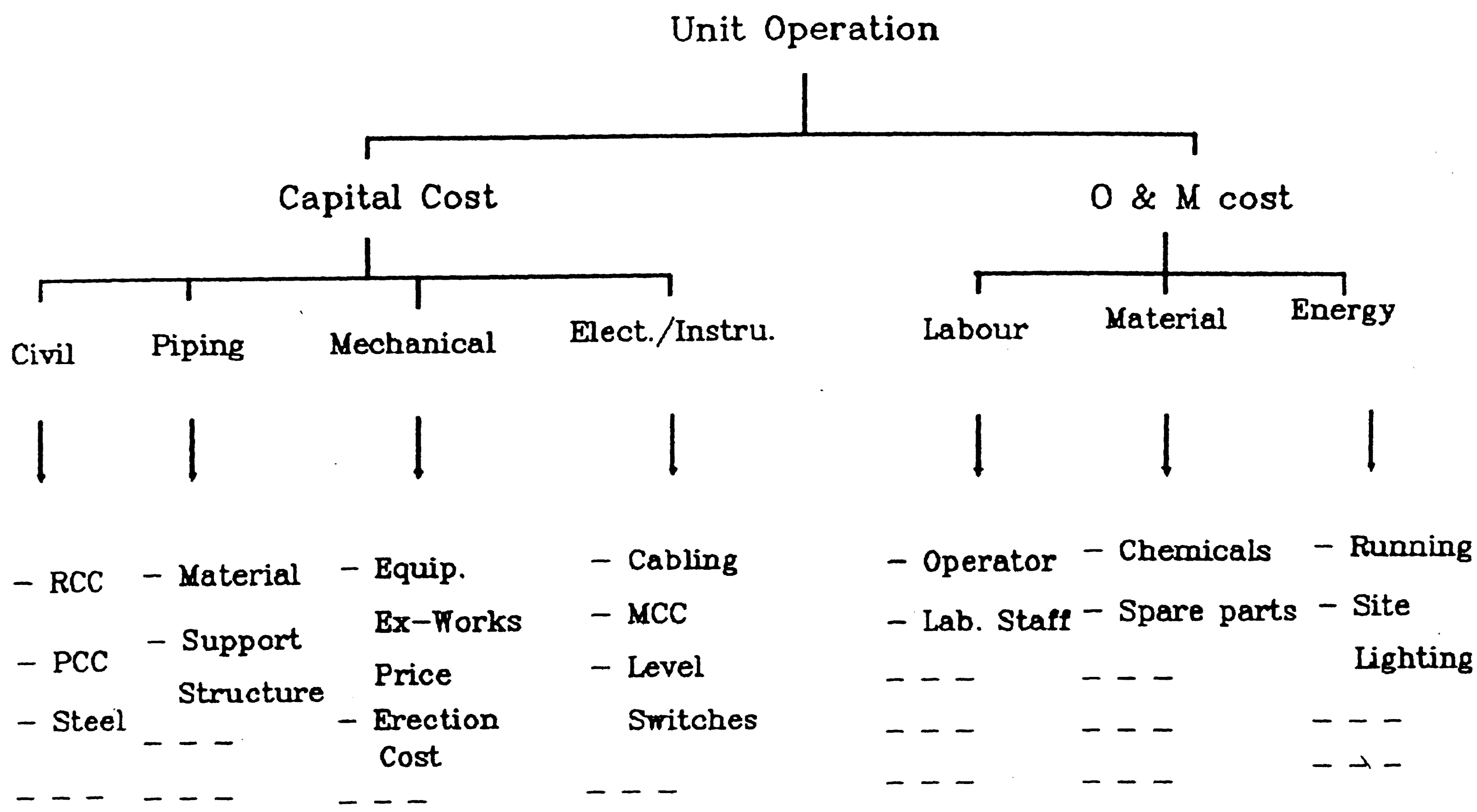



Fig. 2. Breakup of Unit Operation Cost in Terms of Composite Items

In general, an index for a $J_r$ subsystem of rth level which is made up of $N_{r-1}$ subsystems of level (r-1) can be defined as follows.

$$I^r(J_r)\Big|_{J_r = 1 \text{ to } N_r}$$

$$= \frac{\text{Unit cost of subsystem } J_r \text{ of rth level under actual conditions}}{\text{Unit cost of subsystem } J_r \text{ of rth level under reference conditions}}$$

$$= \frac{\text{Sum of cost of } N_{r-1} \text{ subsystems in making subsystem } J_r \text{ of rth level under actual conditions}}{\text{Sum of cost of } N_{r-1} \text{ subsystems in making subsystem } J_r \text{ of rth level under reference conditions}}$$

$$= \frac{\text{Sum of the product of the quantity and unit cost (rate) of the } N_{r-1} \text{ subsystems in making subsystem } J_r \text{ of rth level under actual conditions}}{\text{Sum of the product of the quantity and unit cost (rate) of the } N_{r-1} \text{ subsystems in making subsystem } J_r \text{ of rth level under reference conditions}}$$

Here, $N_r$ and $N_{r-1}$ are the number of subsystems of level r and r-1 respectively.

Thus starting from the first level, cost index can be given as

$$I^1(J_1)\Big|_{J_1 = 1 \text{ to } N_1} = \frac{R^1(J_1)}{R^1_*(J_1)} = \frac{Q^J 1(J_1)\ R^1(J_1)}{Q^J 1(J_1)\ R^1_*(J_1)} \qquad (4)$$

Here, $N_1$ is the number of fundamental subsystems/unit; $I^1(J_1)$ is the index of J th fundamental subsystem, $R^1(J\ )$ and $R^1_*(J\ )$ are the unit costs of the fundamental subsystems under actual and reference conditions respectively, $Q^J 1(J_1)$ is the quantity of $J_1$th fundamental unit required to make a unit of $J_1$th subsystem.

The second level cost index can be expressed as

$$I^2(J_2)\Big|_{J_2 = 1 \text{ to } N_2} = \frac{R^2(J_2)}{R^2_*(J_2)} = \frac{\sum_{J_1=1}^{N_1} Q^J2(J_1) \times R^1(J_1)}{\sum_{J_1=1}^{N_1} Q^J2(J_1) \times R^1_*(J_1)} \qquad (5)$$

Substituting $R^1(J_1) = I^1(J_1) \times R^1_*(J_1)$

$$I^2(J_2)\Big|_{J_2 = 1 \text{ to } N_2} = \frac{R^2(J_2)}{R^2_*(J_2)} = \frac{\sum_{J_1=1}^{N_1} Q^J2(J_1) \times I^1(J_1) \times R^1_*(J_1)}{\sum_{J_1=1}^{N_1} Q^J2(J_1) \times R_*{}^1(J_1)} \qquad (6)$$

Here, $Q^J2(J_1)$ is the quantity of $J_1$th subsystems/units of level 1 required to make $J_2$th subsystem of level 2, and $N_1$ is the number of level 1 subsystems involved in making a subsystem of level 2.

In general, index of nth level, can be expressed as

$$I^n(J_n)\Big|_{J_n = 1 \text{ to } N_n} = \frac{\sum_{J_{n-1}=1}^{N_{n-1}} Q^Jn(J_{n-1}) \times R^{n-1}_*(J_{n-1}) \times I^{n-1}(J_{n-1})}{\sum_{J_{n-1}=1}^{N_{n-1}} Q^Jn(J_{n-1}) \times R^{n-1}_*(J_{n-1})} \qquad (7)$$

In present study, indices upto level 3 are considered for civil works component of capital cost. As explained earlier, basic items constitute the first level, composite items will constitute the second level and the civil works component cost of an unit operation constitute the third level. As far as mechanical equipment cost component of capital cost is concerned only two levels are considered. Labour cost, material cost and the cost of tools and plant for manufacturing being at level 1 and the mechanical equipment cost component constituting the second level.

# 5. METHODOLOGY

## 5.1 Scope

In view of the ultimate objective of the study and the formulation presented, the follow-up methodology was executed in three phases. The first phase involved collection of preliminary data and information on cost and cost estimation procedures for treatment plants. The second phase involved critical analysis of the information/data collected in first phase and to obtain detailed information/data in the required format. In the third phase attempt was made to develope cost curves/functions for selected unit operations. Data/information collection was restricted to two cities viz. Kanpur and Bombay due to limitation of resources. However, this may be considered representative due to the fact that agencies (Consultants, Owners, Contractors, etc.) associated with the major treatment plants are situated in Bombay and can be considered as typical of Indian scenario.

## 5.2 Phase I : Preliminary Information/Data Collection

All concerned agencies viz. government departments (e.g. Pollution Control Boards), owners (e.g. private sector companies), consultants (e.g. Klean Environmental Consultants, Bombay) were contacted through visits to assess the type of information/data that would be available. It was realized that the data regarding total plant cost was difficult to get except for very small plants. Also unit process wise cost data was not available in segregated form with any of the agencies visited during data collection. Few agencies (e.g. Associated Industrial Consultants, AIC, Bombay; Klean Environmental Consultants, Bombay) were having unit operation wise breakup of quantities of items involved, but for item rate contracting, items like RCC, PCC, etc. for all unit operations were added together and no data of cost of unit operation was available separately. Unit operation wise segregation of cost was found with only one agency viz. Environmental Engineering Consultants, Bombay, wherein quotations given by various civil contractors were found to show cost of unit

operation at same time, same location to vary from twenty to fifty percent from each other.

## 5.3 Phase II : Detailed Information/Data

Considering variations in costs for the same unit operation, unavailability of data in the required format, etc., it was decided to synthesise these data from the cost data of basic items. Principles of cost estimation as used in practice has been adopted. Three major components considered are civil works cost, mechanical equipment cost and cost of electrical work.

**5.3.1 Civil works cost:** Civil work cost is estimated through quantity survey of composite items. As an example six unit operations which are most commonly used in practice of wastewater treatment were selected. Range of physical dimensions over which units for these operations are generally constructed was identified from literature (USEPA, 1979; Benjes, 1980). Six to ten units in each operation uniformly distributed over the predetermined feasible range were selected. Proportionate physical dimensions were selected based on general alignment (GA) drawings obtained from various agencies (Consulting firms).

**5.3.1.1 Quantity survey:** Quantities for six items contributing significantly towards cost of unit operation are estimated for each unit. These six items are decided after analysis of the data obtained in Phase I. Following is the brief description of the procedure adopted for estimation of quantities of various major items for selected unit operations.

Screen Chamber: Screening is normally the first unit operation used in wastewater treatment plants. The general purpose of screens is to remove large objects such as rags, paper, plastics and the like. A typical screen chamber consists of a rectangular channel. The floor of the channel is normally 7 to 15 cm lower than the invert of the incoming sewer. The screen channel is designed to prevent the accumulation of grit and other heavy materials into the channel. The channel is normally provided with

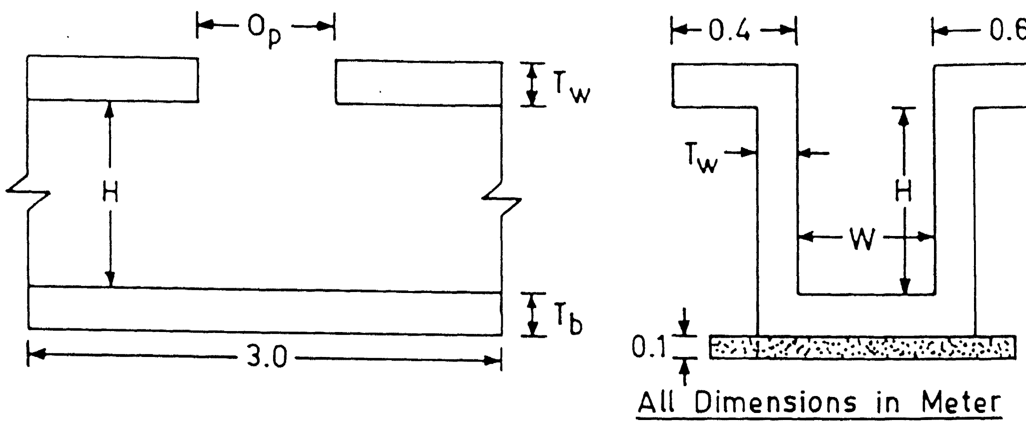
a straight approach, perpendicular to the screen, to assure uniform distribution of screenings over the entire screen area.

Cross sectional area of the screen channel limits the quantity of wastewater that can be safely handled and is the major factor which governs the overall cost of this unit operation and hence taken as capacity parameter. Six screen chambers of varying capacity (Figure 3 and Table 3) are considered in estimating quantities of major items involved in civil works. These dimensions are based on typical GA drawing. Following general assumptions are made while estimating quantities. 1) Quantity of steel is 80 Kg/cum of RCC. 2) 100 mm thick PCC under the base slab. 3) No separate footing as base slab is expected to be sufficiently deep below ground level. 4) Only internal plastering. 5) Appropriate deduction for opening in cover slab.

Grit Chamber: Grit includes sand, dust, cinder and other materials in wastewater that are non putrescible and are heavier than organic matter. The grit in wastewater has specific gravity of 1.5 to 2.7. The organic matter in wastewater has specific gravity around 1.02. Therefore differential sedimentation is a successful mechanism for separation of grit from organic matter.

Nine grit chambers of varying capacity (Figure 4 and Table 4) are considered in estimating quantities of major items involved in civil works. These dimensions are based on typical GA drawing. Following general assumptions are made while estimating quantities. 1) For simplicity only rectangular channel of constant length 10 m and varying cross section resting on 100 mm thick layer of PCC. 2) No special provision to house grit removal mechanism. 3) Only internal plastering. 4) Quantity of steel is 100 Kg/cum of RCC. 5) Waterproofing is along the joint of wall and base slab for a width of one meter.

Aeration Tank: Aeration tank is a biological reactor in activated sludge process. Basic function of BOD reduction is done by suspended biomass which uses biodegradable material as food and the oxygen supplied through air during aeration. Wide range of

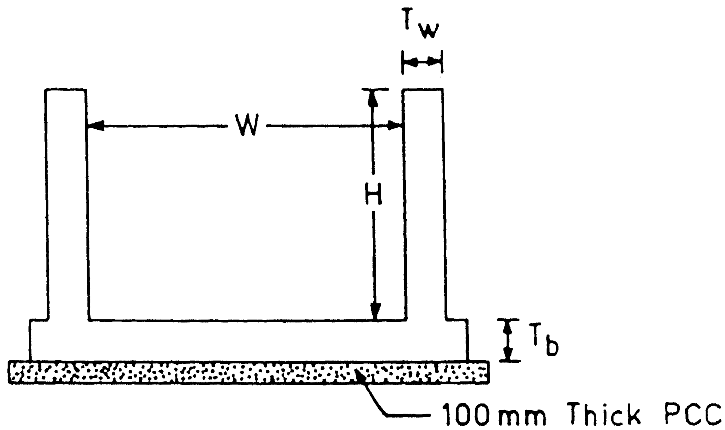



H : Channel Depth ; W : Channel Width ; $T_b$ : Base Slab Thickness ; $T_w$ : Wall Thickness ; $O_p$ : Rake Opening .

Fig. 3. Schematics of Screen Chamber for Quantity Estimation.

Table 3: Specifications of Screen Chambers Considered for Quantity Estimation

| | | | | | | |
|---|---|---|---|---|---|---|
| H | 0.50 | 1.00 | 1.33 | 1.67 | 2.00 | 3.00 |
| W | 0.50 | 0.50 | 1.00 | 1.33 | 1.67 | 2.00 |
| $T_w$ | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 0.15 |
| $T_b$ | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 |
| $O_p$ | 0.75 | 0.75 | 0.75 | 0.75 | 1.00 | 1.00 |




H : Channel Depth; W : Channel Width; $T_b$ : Base Slab Thickness; $T_w$ : Wall Thickness.

Fig. 4. Schematics of Grit Chamber for Quantity Estimation.

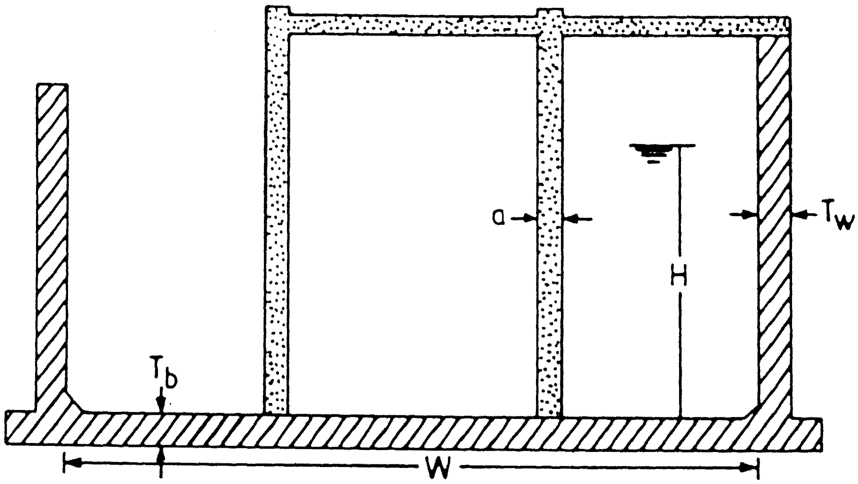
Table 4: Specifications of Grit Chambers Considered for Quantity Estimation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| H | 0.42 | 0.53 | 0.69 | 0.82 | 1.27 | 1.27 | 1.34 | 1.65 | 1.79 |
| W | 1.00 | 1.00 | 1.00 | 1.50 | 1.50 | 2.00 | 2.30 | 2.50 | 3.00 |
| $T_w$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.20 | 0.20 | 0.20 | 0.20 |
| $T_b$ | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| All Dimensions in Meters | | | | | | | | | |

modifications is available in activated sludge process. However, physical configuration of aeration tank is insignificantly dependant on the process modification. Square and rectangular tank are the configurations commonly used. The type of tank to be used depends upon the aeration system used. Aeration system has to fulfill two criteria viz. oxygen supply and mixing. Depth of aeration tank depends upon the depth of influence of aeration device.

Considering importance of aeration tank in activated sludge process, in all 42 rectangular tanks and 36 square tanks (Figure 5 and Table 5) are considered in estimating quantities of major items involved in civil works. Depth is varied from 2.5 m to 5.0 m at the interval of 0.5 m. Thus 7 sets of rectangular type and 6 sets of square type containing 6 units each are considered with varying surface area. Quantity of RCC includes two sets of platform for aerator support and walkway for rectangular tank, and one set for square tank as the aeration device considered is mechanical aerator. The quantity for these being hardly 5 to 8 percent of total RCC for the tank its impact on total cost of unit will be negligible. Hence, the construction cost (civil works) function can be equally useful for other types of aeration devices. The dimensions are based on typical GA drawing. Following general assumptions are made while estimating quantities. 1) Quantity of steel is 100 Kg/cum of RCC. 2) Waterproofing layer of 1 m width along joint of base slab and wall. 3) Base slab resting on ground is assumed to act as raft footing.

Secondary Clarifier: Secondary clarifier is one of the most essential parts of any biological process. If this unit is not properly functional, though the biological reactor is very efficient and soluble BOD of the effluent is low enough, insoluble BOD of the effluent becomes very high and effluent fails to meet the regulatory standard. Circular clarifiers have been constructed with diameter and depth ranging from 4 to 50 m and 2.5 to 4 m respectively. Two types of feeding arrangements viz. center feed and rim feed are commonly used. Also sludge removal mechanisms are of two types, those that scrap the sludge to a central sludge




W : Width of Tank; H : Side Water Depth;
$T_b$ : Thickness of Base Slab; $T_w$ : Thickness of Wall;
a : Size of Support Column.

Fig. 5. Schematic of Aeration Tank for Quantity Estimation.

Table 5: Specifications of Aeration Tanks Considered for Quantity Estimation

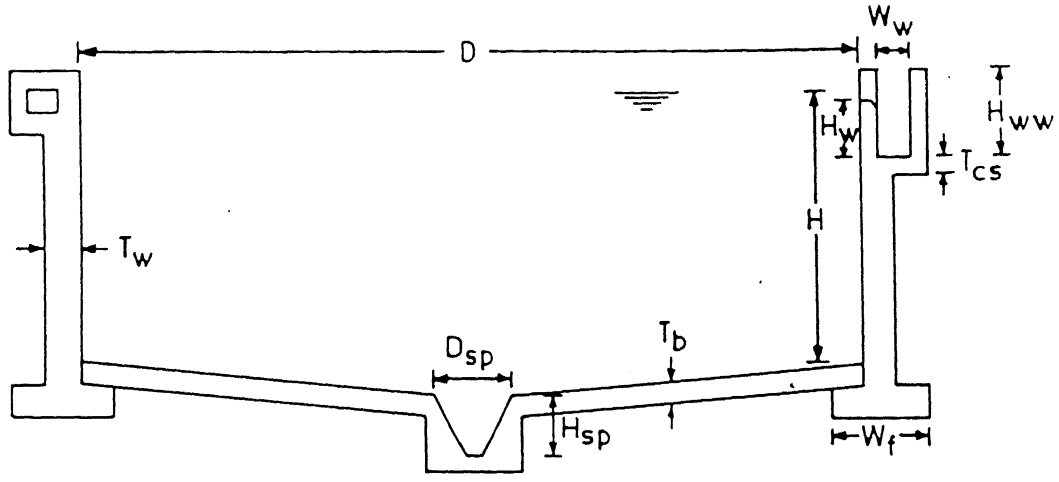
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | 6.0 | 10.0 | 15.0 | 21.0 | 27.0 | 38.0 | 46.0 | 4.0 | 7.0 | 13.5 | 17.5 | 25.0 | 30.5 |
| W | 3.0 | 5.0 | 7.5 | 10.5 | 13.5 | 19.0 | 23.0 | 4.0 | 7.0 | 13.5 | 17.5 | 25.0 | 30.5 |
| $T_w$ | 0.20 | 0.23 | 0.25 | 0.30 | 0.35 | 0.40 | 0.40 | 0.15 | 0.23 | 0.30 | 0.35 | 0.40 | 0.40 |
| $T_b$ | 0.15 | 0.17 | 0.20 | 0.23 | 0.25 | 0.25 | 0.25 | 0.12 | 0.18 | 0.20 | 0.20 | 0.25 | 0.25 |
| a | 0.20 | 0.20 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.20 | 0.20 | 0.23 | 0.23 | 0.23 | 0.23 |
| All Dimensions in Meters | | | | | | | | | | | | | |

collection pit, and those that remove the sludge directly from the tank bottom through suction orifices. Larger tanks are subject to unbalanced radial diffusion and wind action, both of which can reduce the efficiency.

Secondary clarifier circular in shape with central feeding and revolving scrapper mechanism is considered in this work. Effluent overflow weir made up of RCC located near perimeter is considered as outlet device. Ten clarifiers of varying capacity (Figure 6 and Table 6) are considered in estimating quantities of major items involved in civil works. These dimensions are based on GA drawing. Following general assumptions are made while estimating quantities. 1) 75 mm cover of screed (PCC with 40 mm size gravels) over bottom slab. 2) Quantity of steel is 100 Kg/cum of RCC. 3) Waterproofing layer of one meter width along perimeter at the joint of wall and the base slab.

Anaerobic digester: Anaerobic digester results in the break down of sludge into methane, carbon dioxide, unusable intermediate organics and relatively small amount of cellular protoplasm. This process consists of two distinct simultaneous stages of conversion of organic material by acid forming bacteria and gasification of the organic acids by methane forming bacteria. The methane producing bacteria are very sensitive to condition of their environment and require careful control of temperature, pH, excess concentration of soluble salts, metal cations, oxidising compounds and volatile acids. They also show an extreme substrate specificity. These can operate at various loading rates and are therefore not always clearly defined as either standard or high rate. Digesters require periodic cleanout due to buildup of sand and gravel on digester bottom.

Quantity estimation is done for 30 digesters (Figure 7 and Table 7). Diameter varying from 10 m to 35 m at the interval of 5 and the depth varying from 5 to 9 m at the interval of 1 m. The dimensions are based on typical GA drawing. Following general assumptions are made while estimating quantities. 1) RCC quantity of dome shaped roof is estimated by estimating quantity of RCC for

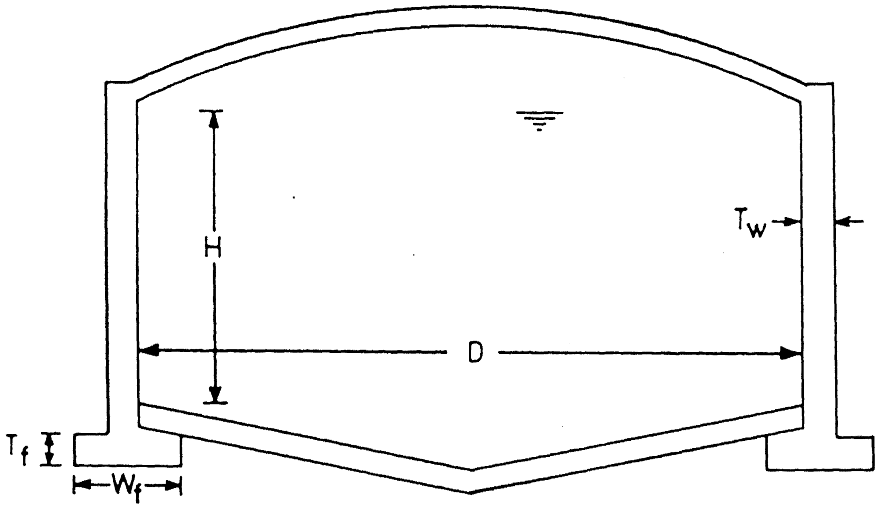



D : Diameter; H : Side Water Depth; $T_w$ : Wall Thickness; $T_b$ : Base Slab Thickness; $D_{sp}$ : Diameter of Sludge Pocket; $H_{sp}$ : Depth of Sludge Pocket; $W_f$ : Footing Width; $H_w$ : Depth of Channel; $W_w$ : Width of Channel; $T_{cs}$ : Thickness of Channel Slab; $H_{ww}$ : Height of Weir Wall.

Fig. 6. Schematics of Secondary Clarifier for Quantity Estimation.

Table 6: Specifications of Secondary Clarifiers Considered for Quantity Estimation

| D | 4.00 | 5.33 | 6.67 | 8.00 | 10.00 | 11.67 | 13.34 | 20.00 | 30.00 | 50.00 |
|---|---|---|---|---|---|---|---|---|---|---|
| H | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $T_w$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.23 | 0.25 | 0.35 |
| $T_b$ | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.20 | 0.23 | 0.30 |
| $D_{sp}$ | 0.75 | 0.75 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 1.25 | 1.50 | 2.00 |
| $H_{sp}$ | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 1.00 | 1.00 | 1.30 |
| $W_f$ | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.40 | 0.45 | 0.60 |
| $H_w$ | 0.15 | 0.15 | 0.15 | 0.20 | 0.20 | 0.25 | 0.25 | 0.25 | 0.30 | 0.30 |
| $W_w$ | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| $T_w$ | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.15 | 0.15 | 0.17 |
| $H_{ww}$ | 0.40 | 0.40 | 0.40 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| All Dimensions in Meters | | | | | | | | | | |




D : Diameter ; H : Side Water Depth ; $T_W$ : Thickness of Wall ; $W_f$ : Width of Footing ; $T_f$ : Thickness of Footing.

Fig. 7. Schematics of Digester for Quantity Estimation.

Table 7: Specifications of Digesters Considered for Quantity Estimation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| D | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| H | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 |
| $T_w$ | 0.300 | 0.340 | 0.390 | 0.425 | 0.450 | 0.310 | 0.340 | 0.390 | 0.425 | 0.450 |
| $W_f$ | 0.60 | 0.68 | 0.78 | 0.85 | 0.90 | 0.62 | 0.68 | 0.78 | 0.85 | 0.90 |
| D | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| H | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 |
| $T_w$ | 0.31 | 0.35 | 0.40 | 0.44 | 0.47 | 0.31 | 0.36 | 0.41 | 0.45 | 0.48 |
| $W_f$ | 0.62 | 0.70 | 0.80 | 0.88 | 0.94 | 0.62 | 0.72 | 0.82 | 0.90 | 0.96 |
| D | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 |
| H | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 |
| $T_w$ | 0.32 | 0.37 | 0.42 | 0.46 | 0.49 | 0.33 | 0.38 | 0.43 | 0.47 | 0.50 |
| $W_f$ | 0.64 | 0.74 | 0.84 | 0.92 | 0.98 | 0.66 | 0.76 | 0.86 | 0.94 | 1.00 |
| $T_f = T_w$ ; | Thickness of Base Slab and RCC Dome = 0.10 m<br>All Dimensions in Meters | | | | | | | | | |

flat roof and then increasing the amount by 30% to account for extra quantity and added cost of form work for the dome. 2) Hopper bottom is provided and the diameter of the tank is increased by 0.5 m to account for added concrete required for sloping. 3) Footing at periphery under wall with width equal to double the wall thickness and depth of footing equal to half the wall thickness. 4) Only internal plastering. 5) Quantity of steel is 80 Kg/cum of RCC. 6) Waterproofing layer of 1 m width along the joint of bottom slab and the wall.

Sludge Drying Beds: Drying beds are used to dewater sludge both by drainage through the sludge mass and by evaporation from surface exposed to air. Collected filtrate is usually returned to the treatment plant. Drying beds usually consist of 15 to 20 cm of sand which is placed over 20 to 25 cm of graded gravels. Vitrified clay pipes laid with open joints are normally used for underdrains. These underdrains have a minimum diameter of 100 mm and a minimum slope of about 1 percent.

Typical unit of size 8 x 12m was considered for quantity estimation in four parts viz. a) long walls, b) short walls, c) bed and d) filtrate collection chamber. Quantity estimation of drying beds with nine different areas with configurations as per shown in Figure 8 assembled from above mentioned parts in appropriate number is carried out. Following general assumptions are made while estimating quantities. 1) Filtrate collection channel 250 x 150 mm deep runs along the length midway between the two flanks of 4 m width each as shown in Figure 8. 2) 150 mm thick sand layer is provided over 250 mm thick gravels. 200 mm thick sludge is expected giving 300 mm free board. 3) Cross section of wall shown in Figure 8 is same for both long and short walls.

**5.3.1.2 Rate analysis:** Once the quantities are calculated for these items, their rates are required for cost computations. Item rates are collected from various agencies (M. K. Talpade and Associates, Bombay; Institute Works Department, I.I.T. kanpur; Maharashtra Water Supply and Sewerage Board, MWSSB, Bombay). Attempt is made to find correlation between item rates collected

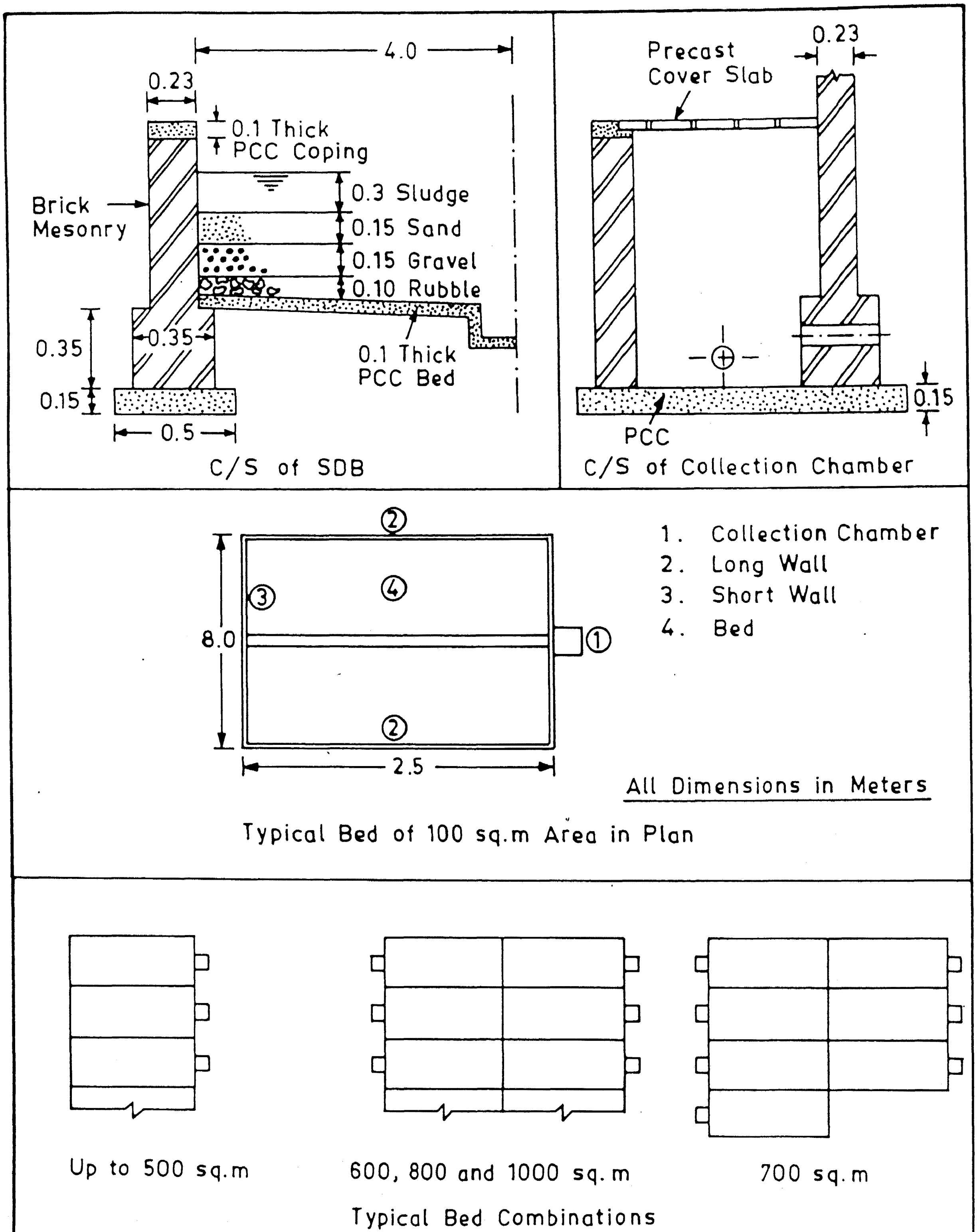



Fig. 8. Schematics of Sludge Drying Beds for Quantity Estimation.

from various sources. These rates were found to vary for the same place and the same time depending upon the source of information. To avoid subjectiveness involved in this, method of rate analysis (Birdie, 1988) for computation of quantities of basic items involved in the composite item is used with little modification. Quantities of basic items for well defined specification of an item do not change over time and geographical location. Thus the only variable subject to time and geographic location is rate of basic items. Basic item rates obtained from various agencies (M/s Thatte and associates, Bombay; M/s Harish Gandhi and Associates, Bombay) are found to be in good agreement at particular time and location.

Table 8 gives the quantities of the basic items, used for the computation. Table 9 gives the rates of these basic items

Table 8. Quantities of Basic Materials for Composite Items

| Composite Item=> Basic Item | PCC cum | RCC cum | B/W cum | Steel MT | Plast$ sq.m | Watp$ sq.m |
|---|---|---|---|---|---|---|
| Cement (Bags) | 4.50 | 8.40 | 1.35 | - | 12.50 | 36.00 |
| Gravel (cum) | 0.90 | 0.84 | - | - | - | 3.60 |
| Sand (cum) | 0.45 | 0.42 | 0.27 | - | 0.25 | 1.81 |
| Bricks (%.Nos.) | - | - | 0.50 | - | - | - |
| Steel (MT) | - | - | - | 1.05* | - | - |
| SL (Nos.) | 0.97 | 1.25 | 0.96 | 15.00 | 10.33 | 22.40 |
| UHDL (Nos.) | 1.45 | 1.50 | 0.70 | - | 3.80 | 6.40 |
| ULDL (Nos.) | 1.45 | 1.50 | 0.70 | 22.50 | 11.00 | 19.20 |

* : Including wastage; $: For 100sq.m; B/W: Brickwork; SL: Skilled labour; UHDL: Unskilled heavy duty labour; ULDL: Unskilled light duty labour; Plast: Plastering; Watp: Waterproofing.

for five consecutive years since 1986. Following are the specifications of the six composite items which contribute significantly to the civil works cost of various unit operations.

Table 9. Basic Item Rates
(Source: M/S Harish Gandhi and Associates, Bombay)

| Item YEAR => | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|
| Cement (Rs/Bag) | 68.0 | 76.0 | 84.0 | 98.0 | 110.0 |
| Gravel (Rs/cum) | 175.0 | 192.5 | 210.0 | 218.0 | 227.5 |
| Sand (Rs/cum) | 192.5 | 210.0 | 218.0 | 227.5 | 236.0 |
| Bricks (Rs/1000) | 525.0 | 560.0 | 625.0 | 625.0 | 650.0 |
| Steel (Rs/MT) | 8150.0 | 9268.0 | 9650.0 | 9650.0 | 13470.0 |
| SL (Rs/d) | 80.0 | 90.0 | 100.0 | 100.0 | 120.0 |
| UHDL (Rs/d) | 30.0 | 35.0 | 40.0 | 45.0 | 50.0 |
| ULDL (Rs/d) | 20.0 | 25.0 | 30.0 | 35.0 | 40.0 |

SL: Skilled labour; UHDL: Unskilled heavy duty labour; ULDL: Unskilled light duty labour.

PCC : Plain cement concrete with 2 cm gauge stone ballast, coarse sand and cement in proportion of 6:3:1, including supply of all material, labour and T & P complete item of work.

RCC : Reinforced cement concrete in proportion of 1:1.5:3 with cement, sand, and aggregate including supply of all materials, T & P, centering, shuttering, scaffolding, etc. required for complete work excluding steel reinforcement.

Brickwork : First class brickwork, in 1:6 cement sand mortar including supply of all materials, labour, T & P , etc. complete item of work.

Plastering : 20 mm thick, 1:6 cement sand mortar plaster including supply of all materials, labour, T & P, etc including raking and watering for completion of work.

Steel : Steel as reinforcement in RCC, brought to required shape as necessary including bending for proper completion of work including supply of all materials including wastage, overlapping, and hooks.

Waterproofing : 40 mm thick damp proof coarse of cement concrete of 1:1.5:3 proportion with sand and aggregate including waterproofing compound, including supply of all materials, labour, T & P, etc. for complete item of work.

### 5.3.2 Piping cost

Detailed analysis of cost of piping work is not done in this study. For the purpose of illustration of unit operation cost and the index for the same, the cost of piping is considered to be ten percent of the cost of civil work.

### 5.3.3 Mechanical equipment cost

Due to unavailability of separate cost data for basic units of mechanical equipment cost, these costs are worked out based on the data collected on ex-works prices from manufacturers. For mechanical equipment cost component of capital cost, cost of material, cost of labour and the cost of tools and plants used in manufacturing process are considered as basic items at level 1 as explained in the previous chapter. For the formulation of cost index for mechanical equipments, after consultation with a leading manufacturing company, it is assumed that 44% of the equipment cost is contributed by material cost, 39% is contributed by labour charges and 17% is contributed by the charges for tools and plants. As an example two unit operations, namely aeration employing low speed surface aerators and clarification are considered, without the pumps for recirculation.

**5.3.3.1 Aeration:** Energy required for various volumes of tank ranging from 50 cum to 4000 cum, at various energy levels (0.01, 0.02, 0.03, 0.05, 0.075, and 0.1 HP/cum) was computed. Best possible combination of low speed aerators of available capacities is considered to obtain the cost.

Budgetary ex-works prices for various capacities of aerators were collected from three leading manufacturers, which

are shown in Table 10. These prices revel that there is no significant variation in prices from three sources.

Table 10. Ex-Works Prices (Rs. in Lacs) for Surface Aerators

| HP => | 3.0 | 5.0 | 7.5 | 10.0 | 15.0 | 20.0 | 25.0 | 30.0 | 40.0 | 50.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Source I | -- | 0.77 | 0.85 | 1.35 | 1.40 | 1.80 | 1.98 | 2.30 | 2.82 | 3.70 |
| Source II | 0.34 | 0.73 | 0.90 | 1.27 | 1.41 | -- | 2.01 | -- | 2.75 | 3.35 |
| Source III | -- | 0.75 | -- | 1.00 | 1.50 | 1.60 | 2.00 | -- | -- | 3.50 |

**5.3.3.2 Clarification:** Half bridge type centrally driven scraper mechanism is considered as mechanical equipment for secondary clarifier. Budgetary ex-works prices, which are normally quoted by diameter of the tank were collected for various diameters from a leading company.

### 5.3.4 Electrical works cost

Detailed analysis of cost of electrical work is not done in this study. For the purpose of illustration of unit operation cost and the index for the same, the cost of electrical work is considered to be 20 percent of the cost of mechanical equipment involved.

## 5.4 Phase III: Curve Fitting

Regression analysis is required to obtain values of unknown parameters in an equation which governs the available data points. Regardless of whether the equation is linear or non linear in parameters, a criterion for determining the best model parameters is required. This requirement is commonly satisfied by the least square method in which sum of squares of the residuals of experimental values and predicted values is minimised. Various algorithms are available for parameter estimation using least square method. In the present work Marqardt (1963) BSOLVE REGRESSION ALGORITHM is used to obtain quantity and cost functions for various unit operation component costs.

# 6. SYNTHESIS AND APPLICATION OF RESULTS

The approach presented in this study for rapid estimation of cost of treatment works is illustrated with the help of data collected/built-up based on the principles and practices followed by engineers in quantity survey and cost estimation using general alignment (GA) drawings of various unit operations. Cost curves/functions are developed for the capital cost of unit operation. Emphasis is given on the civil works component of the capital cost. For civil works cost, basic item rates for 1988 as reported in Table 9 are taken as that of reference conditions.

## 6.1 Synthesis

For each unit operation, parameter(s) which significantly influence the quantities of various items involved in building the unit operation are identified. These parameter(s) are called as capacity parameter(s) and taken as independent variable(s) for quantity and cost curves/functions. Most of the results are shown in graphical form and the regression equation developed along with relevant statistical parameters are presented on corresponding graphs. Table 11 presents a summary of the results for various unit operations, giving capacity parameters, cost component(s) considered, items considered for quantity estimation and reference for the figure/table in which corresponding curve(s)/function(s) are presented.

## 6.2 Application

To rapidly estimate cost of selected unit operation two approaches can be followed. The first approach involves the following steps.

1) Read/compute quantities of various composite items from quantity curve(s)/function(s).

2) Compute unit operation cost by summing up the product of corresponding quantities and rates of composite items at actual conditions.

3) In case composite item rates are not available, compute composite item rates using current rates of basic items, and quantities of basic items given in Table 9.

Table 11. Summary of the Results for Various Unit Operations

| Unit Operation | Capacity Parameter | Cost Component | Curve/ Function | Figure/ Table |
|---|---|---|---|---|
| Screen Chamber | C/S Area | Civil | Quantity<br>Cost | Figure 9<br>Figure 10 |
| Grit Chamber | C/S Area | Civil | Quantity<br>Cost | Figure 11<br>Figure 12 |
| Aeration Tank (Square) | Depth/Area<br>Depth<br>Area<br>Volume | Civil<br><br><br>Mechanical | Quantity<br>Cost<br>Cost<br>Cost | Table 12<br>Figure 13<br>Figure 14<br>Figure 25 |
| Aeration tank (Rectangular) | Depth & Area<br>Depth<br>Area<br>Volume | Civil<br><br><br>Mechanical | Quantity<br>Cost<br>Cost<br>Cost | Table 12<br>Figure 15<br>Figure 16<br>Figure 26 |
| Secondary Clarifier | Surface Area | Civil<br><br><br><br>Mechanical | Quantity*<br>Quantity+<br>Cost*<br>Cost+<br>Cost | Figure 17<br>Figure 18<br>Figure 19<br>Figure 20<br>Figure 27 |
| Digester | Depth & Area<br>Depth<br>Diameter | Civil | Quantity<br>Cost<br>Cost | Table 12<br>Figure 21<br>Figure 22 |
| Sludge Drying Beds | Surface Area | Civil | Quantity<br>Cost | Figure 23<br>Figure 24 |

* : Corresponds to fixed part; + : Corresponds to variable part

Note: For convenience all figures and tables are arranged in sequence at the end of this chapter.

The second approach involves following steps.

1) Read/compute cost of selected unit operation from the cost curve(s)/function(s).

2) Use the index (Figure 28) at actual conditions to transform the cost at actual conditions.

3) Compute the required index using current rates of basic items, rates of basic items under reference conditions (Table 9) and method of rate analysis (Table 8). In case current rates of basic items under actual conditions are not available one can use the indices which have been computed in this work as illustrative example (Figure 28).

Figure 28 shows variation in cost indices over a period of five years from 1986 to 1990. Cost indices used here are computed based on the data built-up for rates at various levels, considering 1988 as base year i.e. index value unity.

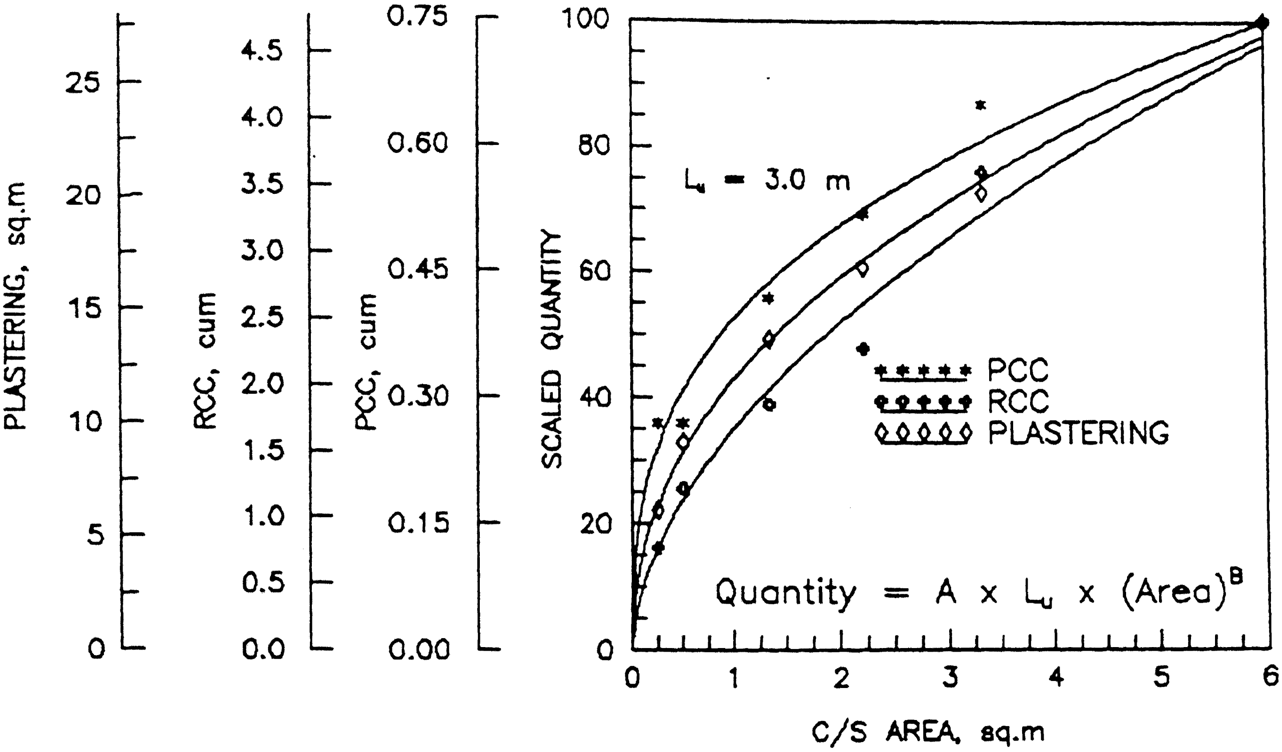
Indices for basic materials show considerable difference in the nature of variation. Compared to basic indices difference in nature of variation in composite item indices is less. This difference in nature of variation in indices is further reduced in case of indices for civil work component of capital cost. Thus a common single index value can be used for civil work cost of various unit operations.

In order to check the validity of indices, the same are compared (Figure 29) with the observed indices computed from civil work cost of three unit operations obtained from a consulting firm against the indices computed from the data built-up in this work.The computed indices are in good correlation with the observed indices.

Table 12. Quantity Functions for Aeration Tanks and Digester

| Unit Operation | Quantity Function |
|---|---|
| Aeration Tank (Square) | PCC (cum) = $0.244 \cdot A^{0.833}$<br>RCC (cum) = $0.55 \cdot A^{0.9} \cdot D^{0.5}$<br>Steel (MT) = 0.1 . RCC (cum)<br>PL (sq.m) = $5.02 \cdot A^{0.73} \cdot D^{0.5} + A^{0.03} \cdot D^{1.25}$<br>WP (sq.m) = $4.0 \cdot A^{0.5}$ |
| Aeration Tank (Rectangular) | PCC (cum) = $0.238 \cdot A^{0.889}$<br>RCC (cum) = $1.16 \cdot A^{0.6} \cdot D + 0.17 \cdot A^{1.02} - 0.05\ D^{0.99}$<br>Steel (MT) = 0.1 . RCC (cum)<br>PL (sq.m) = $2.0 \cdot A^{0.6} \cdot D + A^{1.07} \cdot D^{0.25}$<br>WP (sq.m) = $4.243 \cdot A^{0.5}$ |
| Digester | PCC (cum) = $0.0785 \cdot (DIA + 0.5)^{2.0}$<br>RCC (cum) = $0.655 \cdot DIA^{1.4167} \cdot D^{0.964}$<br>Steel (MT) = 0.08 . RCC<br>PL (sq.m) = $3.14 \cdot (D + 0.5) \cdot DIA + 0.785 \cdot (DIA + 0.5)^{2.0}$<br>WP (sq.m) = $3.14 \cdot DIA$ |

A : Area; D : Depth; DIA: Diameter; PL : Plastering; WP : Water-proofing.




| ITEM, unit | SCALE* | A | B | R | S | N |
|---|---|---|---|---|---|---|
| PCC, cum | 0.75 | 0.1317 | 0.3570 | 0.9889 | 0.0337 | 6 |
| RCC, cum | 4.78 | 0.5719 | 0.5619 | 0.9890 | 0.2540 | 6 |
| PL, sq.m | 28.00 | 4.0317 | 0.4564 | 0.9980 | 0.5300 | 6 |
| Steel, MT | - | 0.0457 | 0.5619 | 0.9890 | 0.2540 | 6 |
| WP, sq.m | - | 2.0000 | 0.0000 | 1.0000 | 0.0000 | 6 |

* Equivalent to 100; WP = Waterproofing; PL = Plastering

Fig. 9. Variation in Civil Works Quantities with C/S Area for Screen Chambers

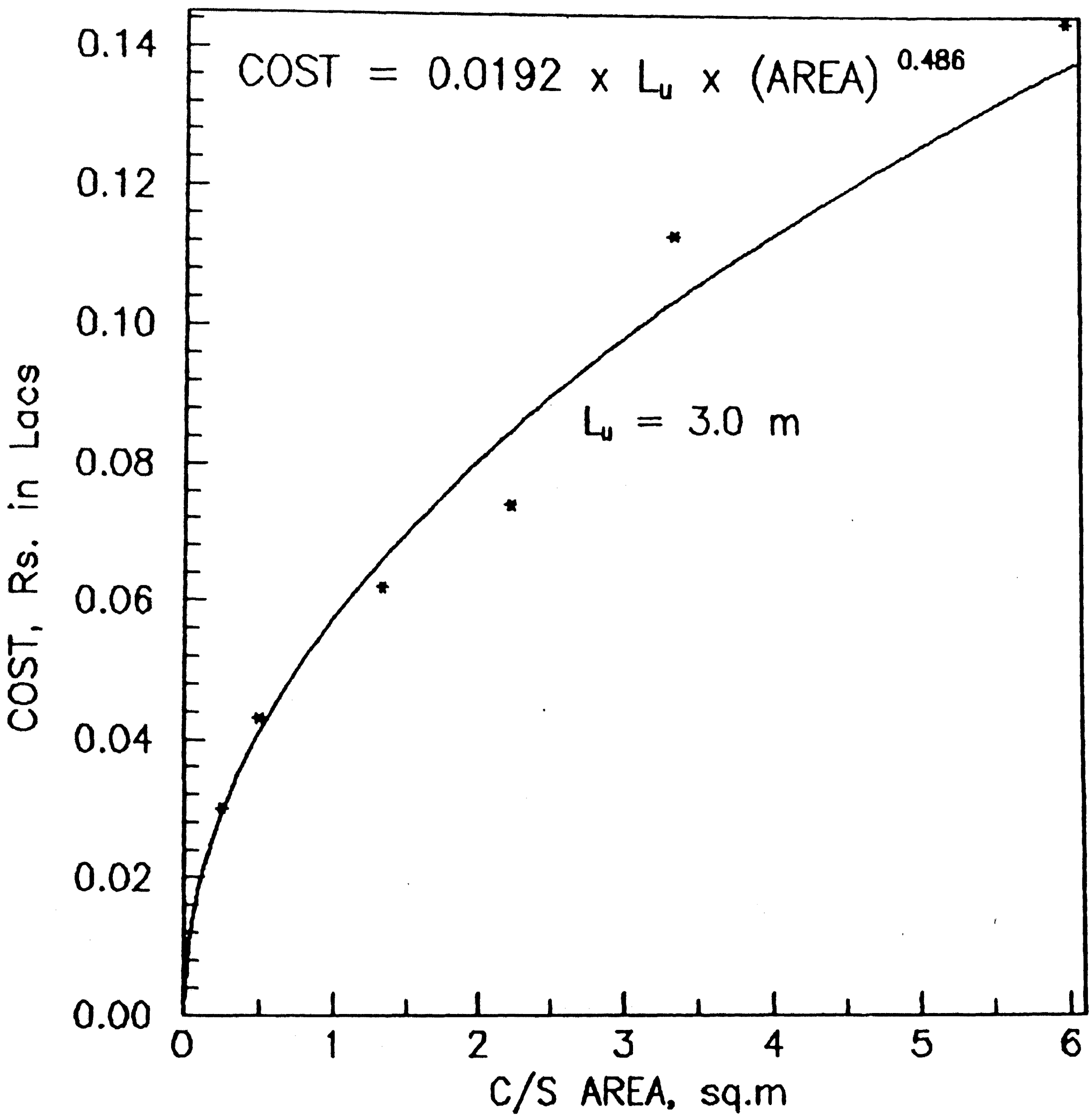
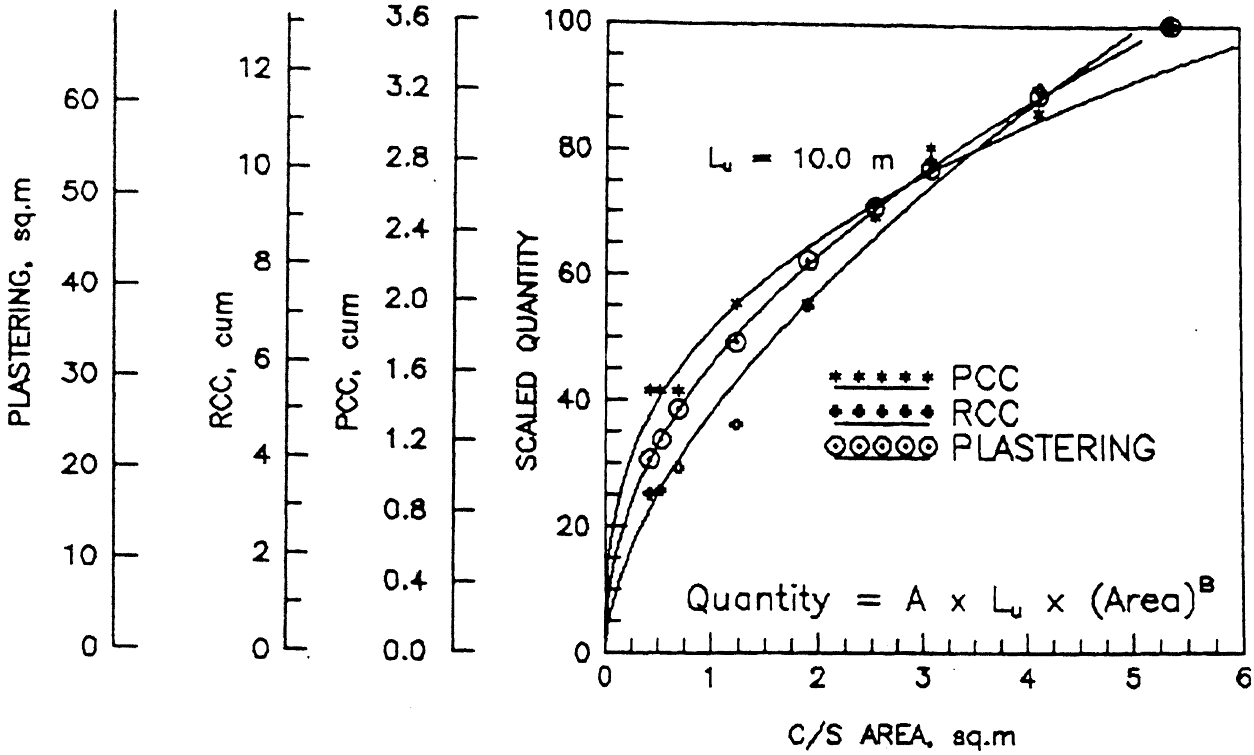



Fig. 10. Variation in Cost of Screen Chambers with C/S Area




| ITEM, unit | SCALE* | A | B | R | S | N |
|---|---|---|---|---|---|---|
| PCC, cum | 3.60 | 0.1186 | 0.3557 | 0.9780 | 0.1780 | 9 |
| RCC, cum | 13.16 | 0.5035 | 0.5935 | 0.9916 | 0.5300 | 9 |
| PL, sq.m | 69.80 | 3.1896 | 0.4669 | 0.9998 | 0.3500 | 9 |
| Steel, MT | - | 0.0504 | 0.5935 | 0.9916 | 0.5300 | 9 |
| WP, sq.m | - | 2.0000 | 0.0000 | 1.0000 | 0.0000 | 9 |
| * Equivqlent to 100; WP = Water proofing; PL = Plastering | | | | | | |

**Fig. 11. Variation in Civil Works Quantities with C/S Area for Grit Chambers**

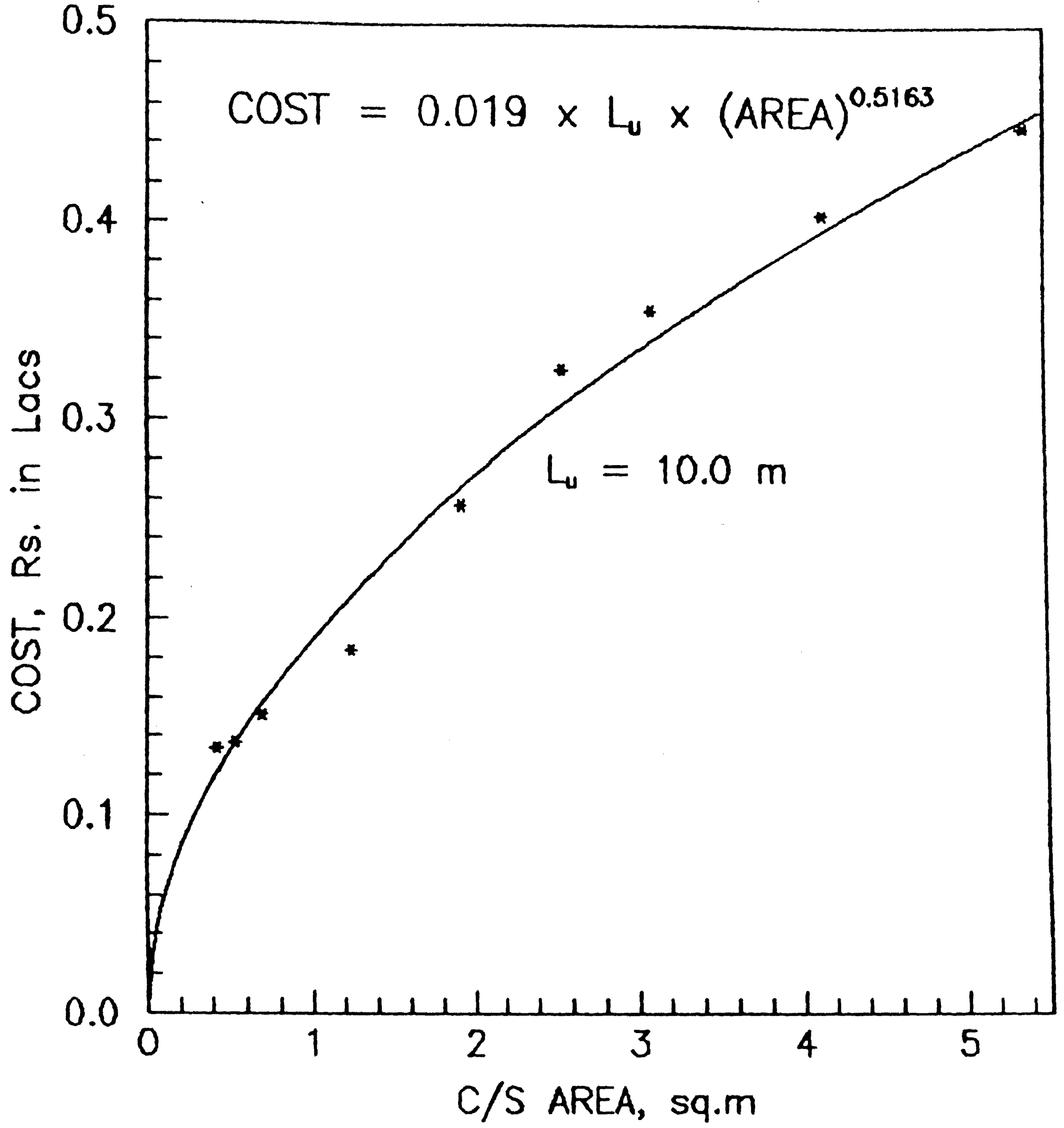
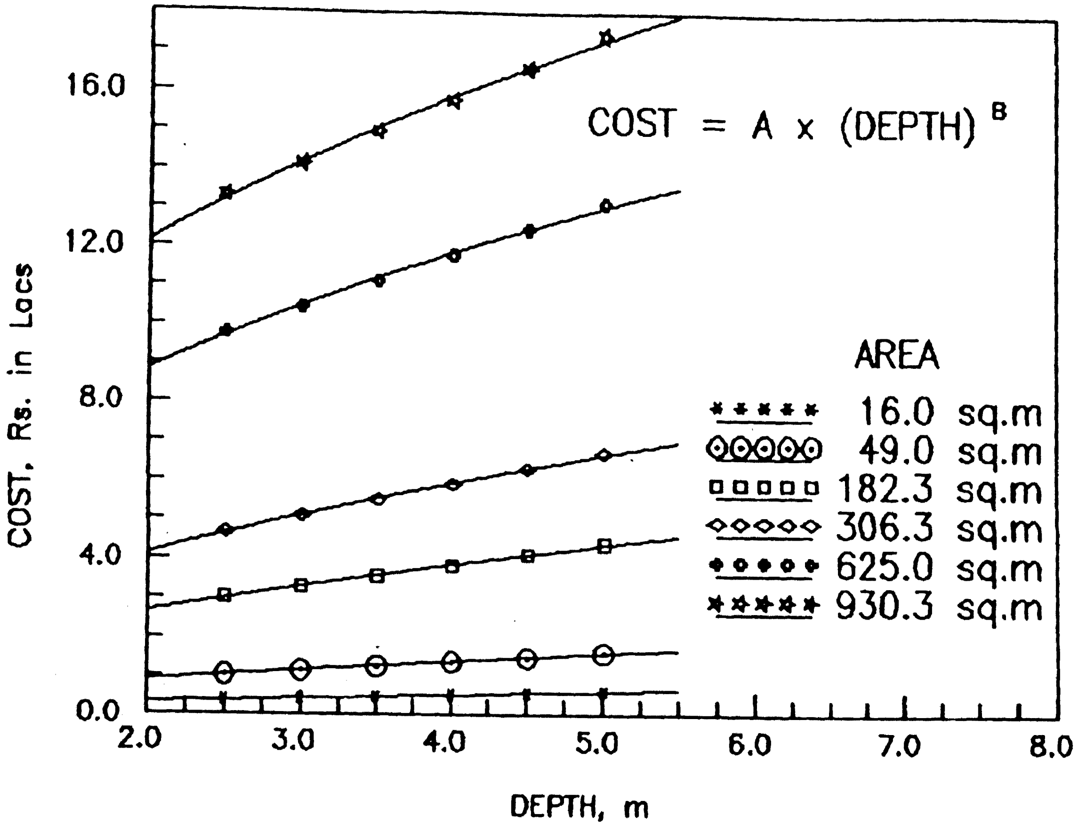
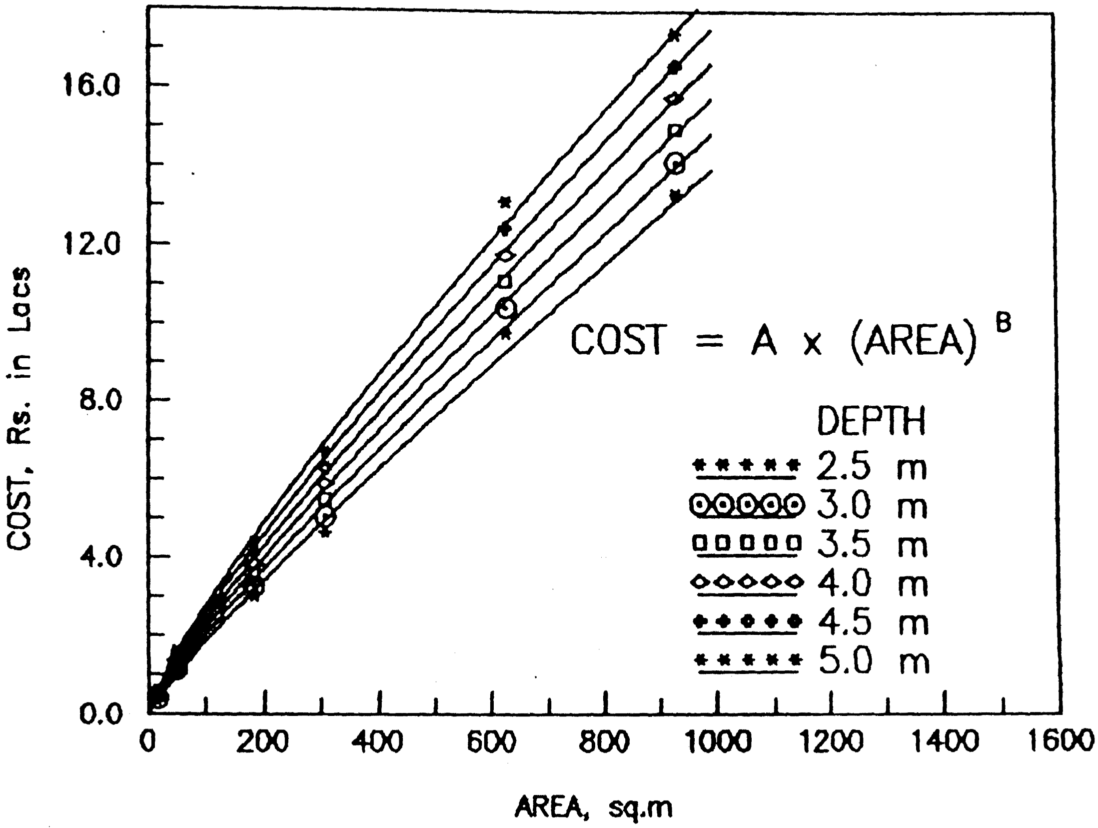



Fig. 12. Variation in Cost of Grit Chambers with C/S Area



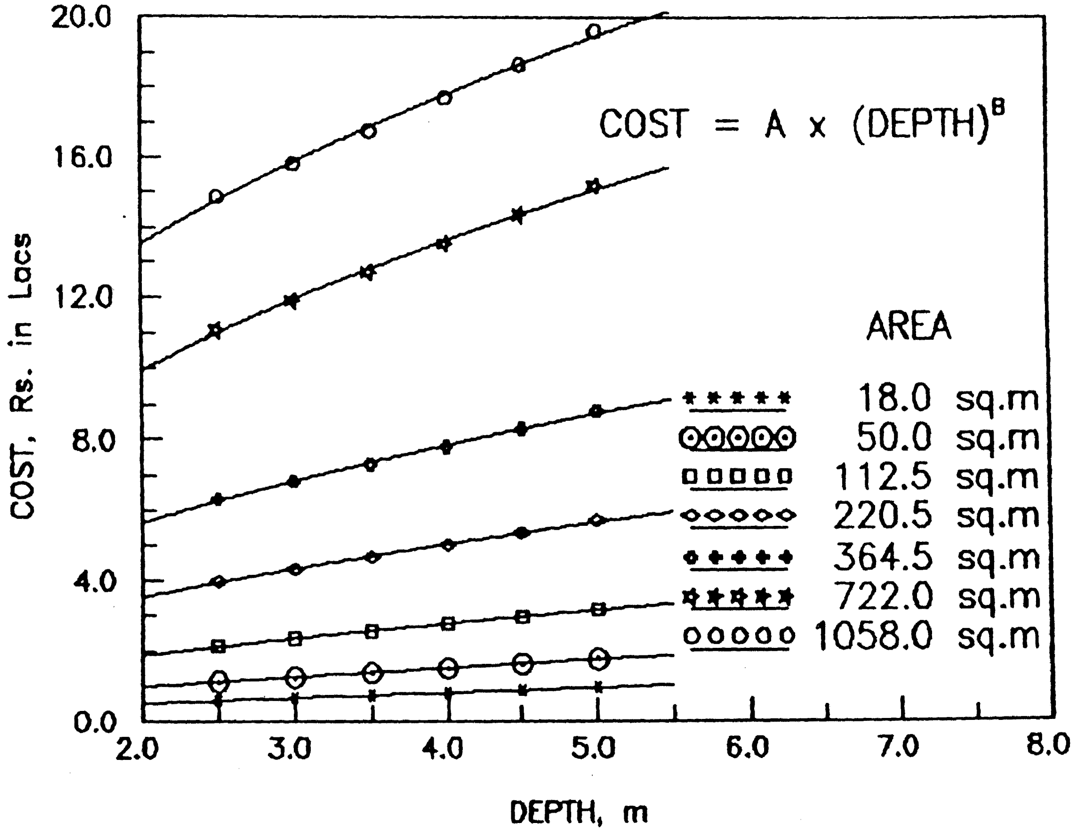

| AREA, sq.m | A | B | R | S | N |
|---|---|---|---|---|---|
| 16.0 | 0.1968 | 0.6905 | 0.9994 | 0.0032 | 6 |
| 49.0 | 0.5754 | 0.6344 | 0.9993 | 0.0086 | 6 |
| 182.3 | 1.8149 | 0.5424 | 0.9988 | 0.0278 | 6 |
| 306.3 | 2.8673 | 0.5236 | 0.9988 | 0.0416 | 6 |
| 625.0 | 6.5745 | 0.4251 | 0.9983 | 0.0815 | 6 |
| 930.3 | 9.2800 | 0.3871 | 0.9979 | 0.1094 | 6 |

Fig. 13. Variation in Cost of Square Tank with Depth



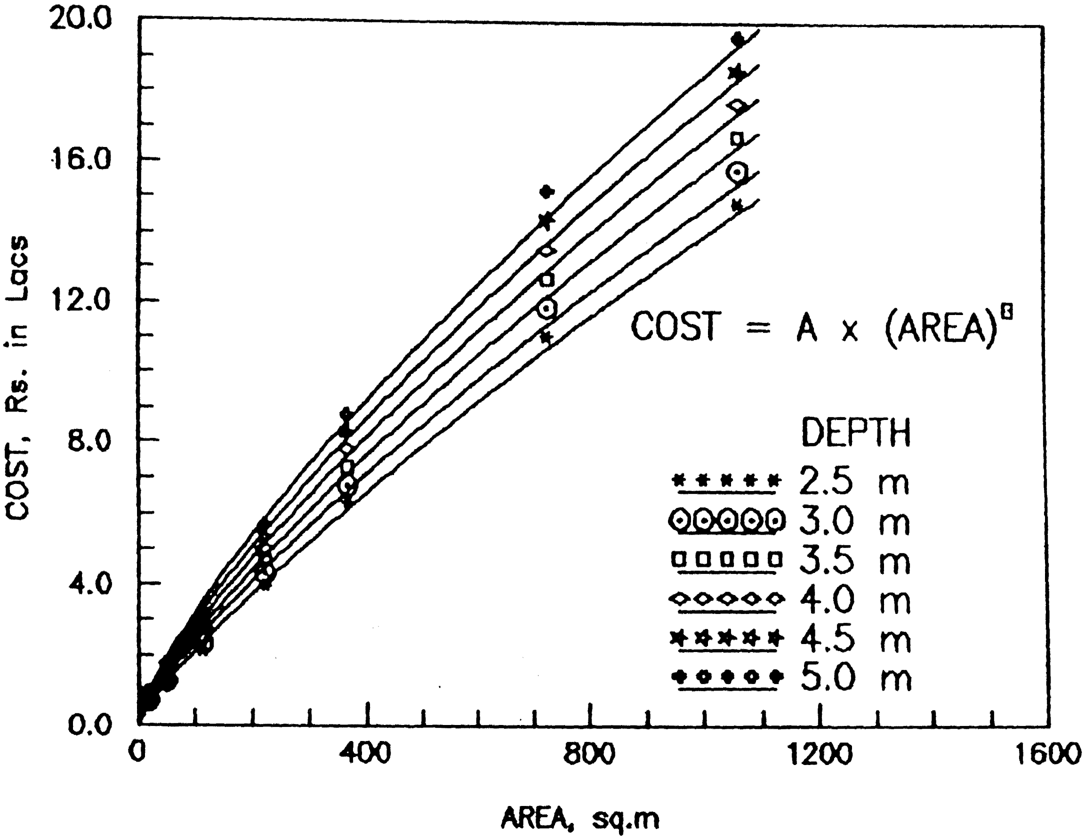

| DEPTH, m | A | B | R | S | N |
|---|---|---|---|---|---|
| 2.5 | 0.0336 | 0.8747 | 0.9989 | 0.2875 | 6 |
| 3.0 | 0.0390 | 0.8617 | 0.9990 | 0.2961 | 6 |
| 3.5 | 0.0447 | 0.8502 | 0.9990 | 0.2979 | 6 |
| 4.0 | 0.0500 | 0.8393 | 0.9990 | 0.3067 | 6 |
| 4.5 | 0.0570 | 0.8307 | 0.9991 | 0.3098 | 6 |
| 5.0 | 0.0633 | 0.8228 | 0.9991 | 0.3142 | 6 |

Fig. 14. Variation in Cost of Square Tank with Area



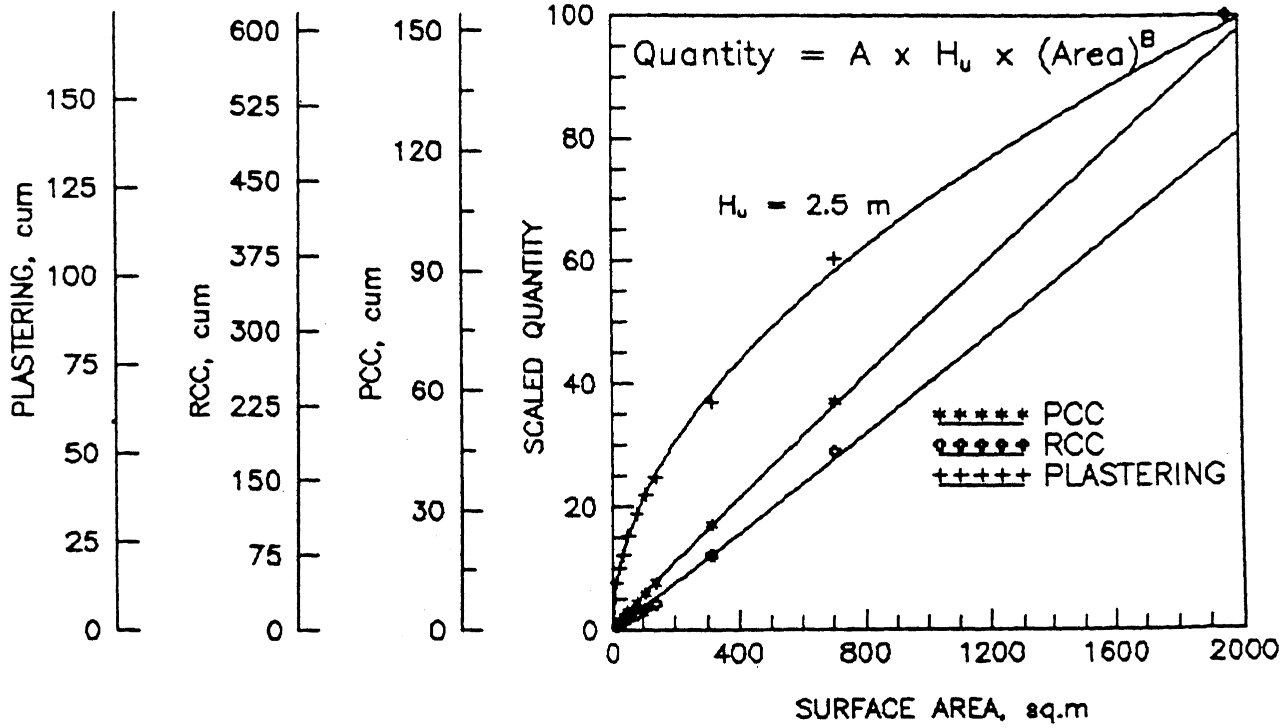

| AREA, sq.m | A | B | R | S | N |
|---|---|---|---|---|---|
| 18.0 | 0.3092 | 0.7058 | 0.9995 | 0.0047 | 6 |
| 50.0 | 0.6266 | 0.6440 | 0.9993 | 0.0100 | 6 |
| 112.5 | 1.2534 | 0.5765 | 0.9991 | 0.0189 | 6 |
| 220.5 | 2.4594 | 0.5172 | 0.9988 | 0.0347 | 6 |
| 364.5 | 4.0286 | 0.4814 | 0.9986 | 0.0550 | 6 |
| 722.0 | 7.2228 | 0.4577 | 0.9985 | 0.0946 | 6 |
| 1058.0 | 10.2252 | 0.4000 | 0.9981 | 0.1213 | 6 |

Fig. 15. Variation in Cost of Rectangular Tank with Depth




| DEPTH, m | A | B | R | S | N |
|---|---|---|---|---|---|
| 2.5 | 0.0503 | 0.8141 | 0.9997 | 0.2553 | 7 |
| 3.0 | 0.0630 | 0.7895 | 0.9996 | 0.3430 | 7 |
| 3.5 | 0.0691 | 0.7857 | 0.9994 | 0.6432 | 7 |
| 4.0 | 0.0783 | 0.7760 | 0.9995 | 0.3523 | 7 |
| 4.5 | 0.0876 | 0.7676 | 0.9994 | 0.3808 | 7 |
| 5.0 | 0.0972 | 0.7599 | 0.9993 | 0.4075 | 7 |

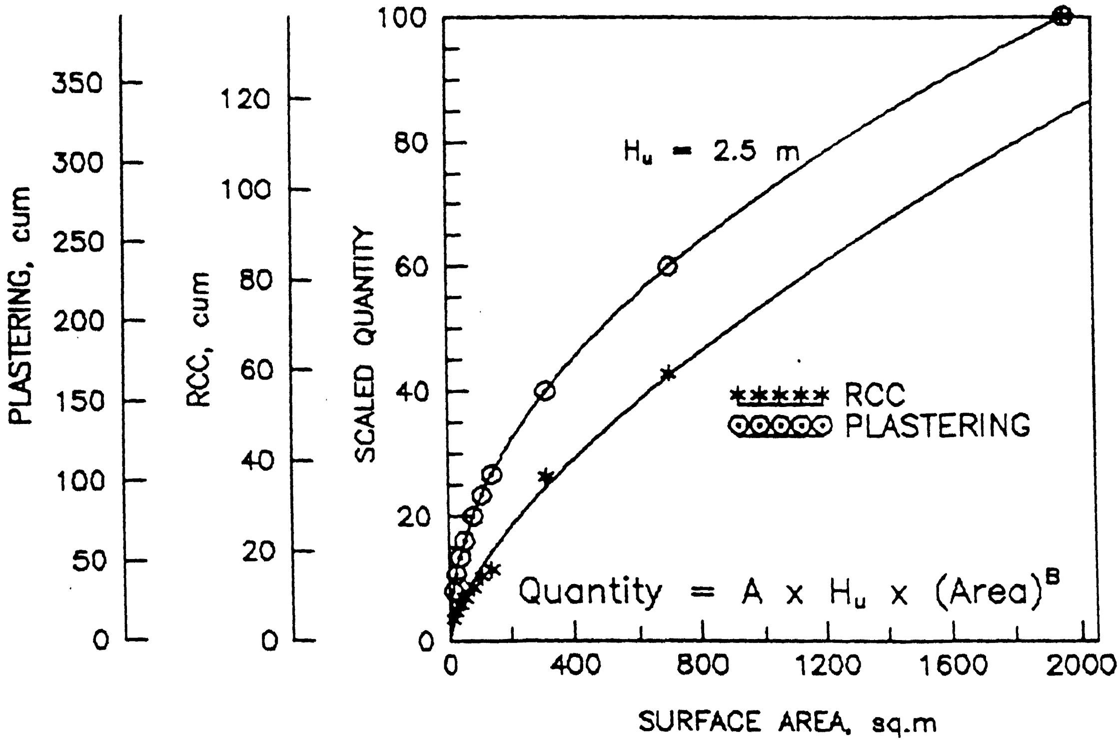
Fig. 16. Variation in Cost of Rectangular Tank with Area




| ITEM, unit | SCALE* | A | B | R | S | N |
|---|---|---|---|---|---|---|
| PCC, cum | 154.30 | 0.0471 | 0.9414 | 0.9990 | 2.1870 | 10 |
| RCC, cum | 618.40 | 0.0880 | 1.0170 | 0.9978 | 45.0100 | 10 |
| PL, sq.m | 174.51 | 1.4440 | 0.5098 | 0.9995 | 1.8220 | 10 |
| Steel, MT | - | 0.0088 | 1.0170 | 0.9978 | 45.0100 | 10 |
| WP, sq.m | - | 1.4180 | 0.5000 | 1.0000 | 0.0000 | 10 |

* Equivqlent to 100; WP = Waterproofing; PL = Plastering

Fig. 17. Variation in Civil Works Quantities with Surface Area for Fixed Part of Secondary Clarifier




| ITEM, unit | SCALE* | A | B | R | S | N |
|---|---|---|---|---|---|---|
| RCC, cum | 138.40 | 0.3220 | 0.6581 | 0.9959 | 7.4770 | 10 |
| PL, sq.m | 392.70 | 3.5457 | 0.5000 | 1.0000 | 0.5540 | 10 |
| Steel, MT | - | 0.0322 | 0.6581 | 0.9959 | 7.4770 | 10 |
| * Equivqlent to 100; PL = Plastering | | | | | | |

**Fig. 18. Variation in Civil Works Quantities with Surface Area for Variable Part of Secondary Clarifier**

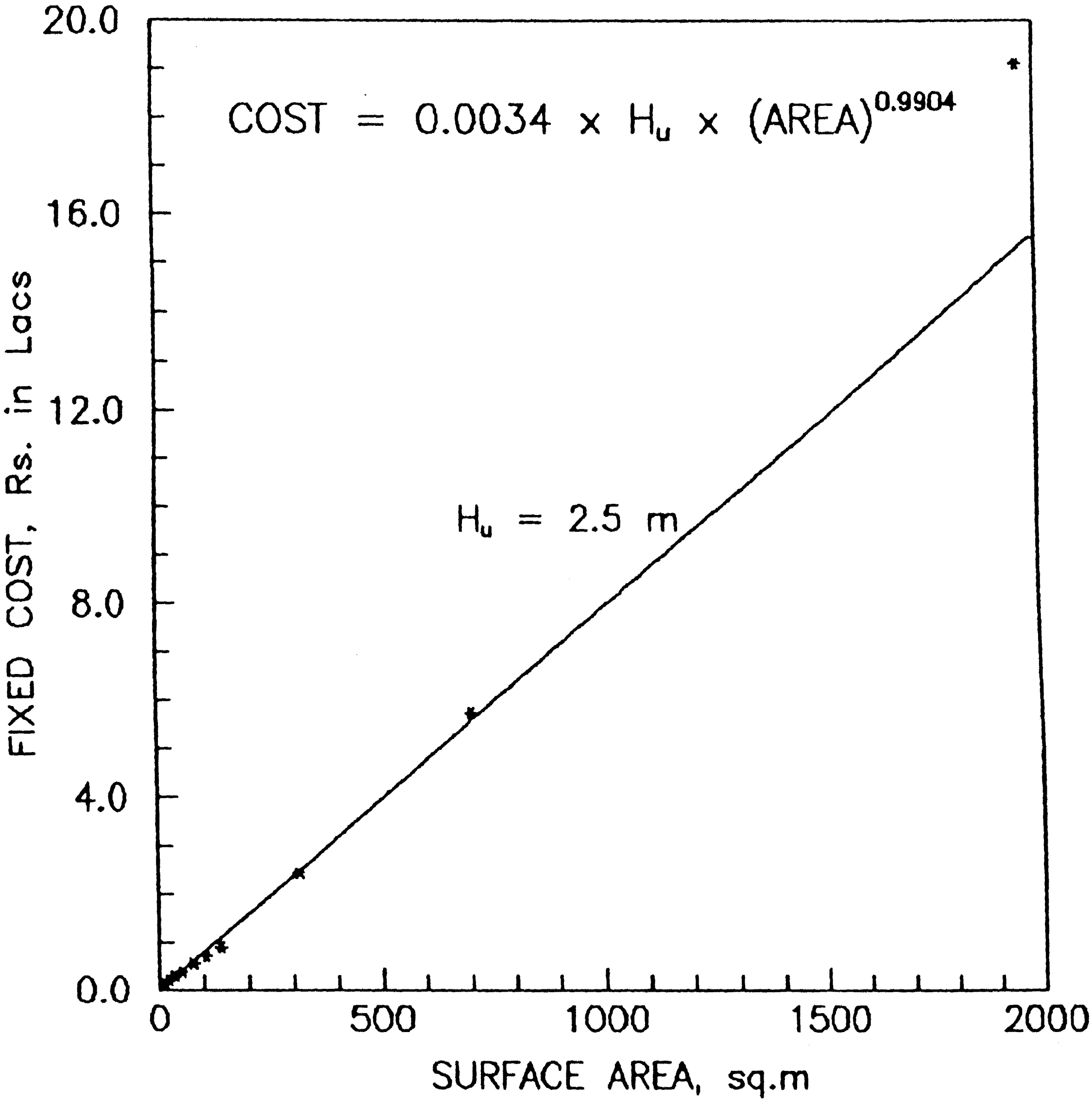



Fig. 19. Variation in Cost of Fixed Part of Secondary Clarifier with Surface Area

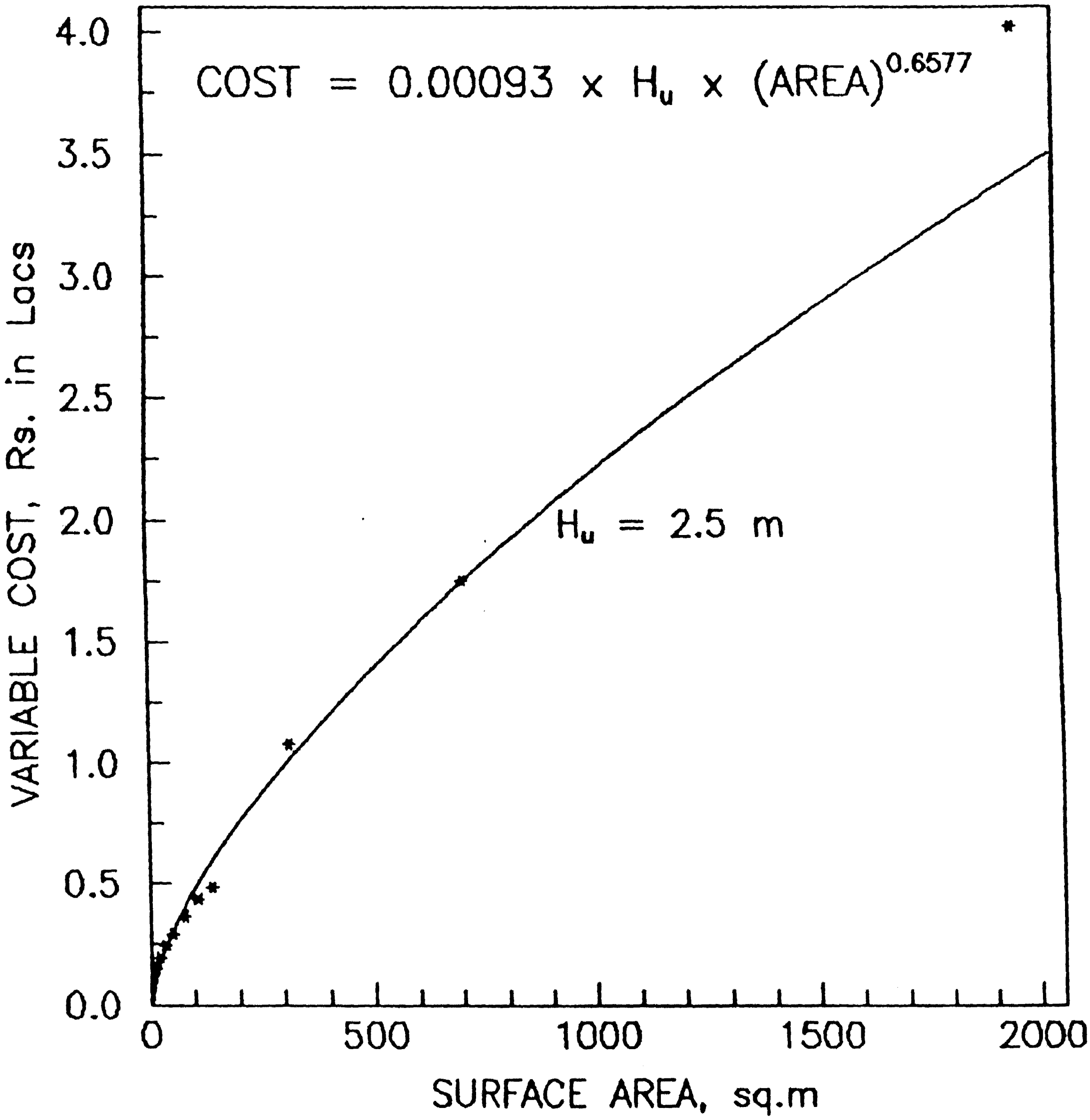
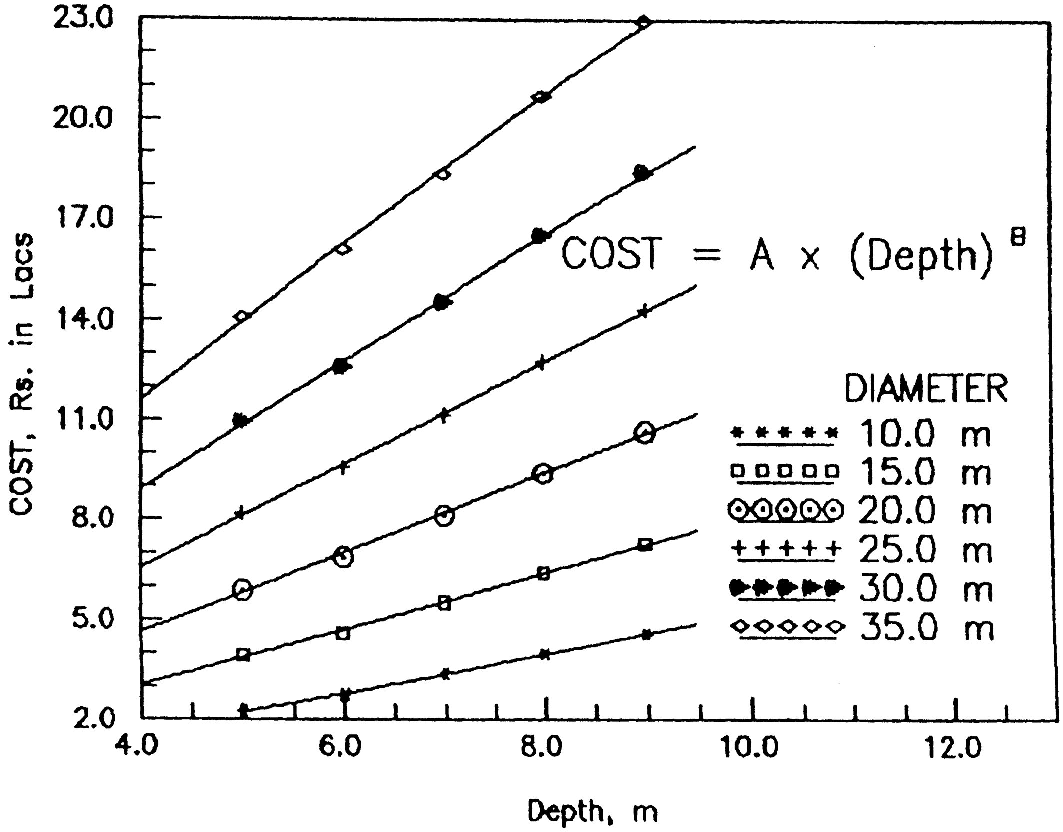
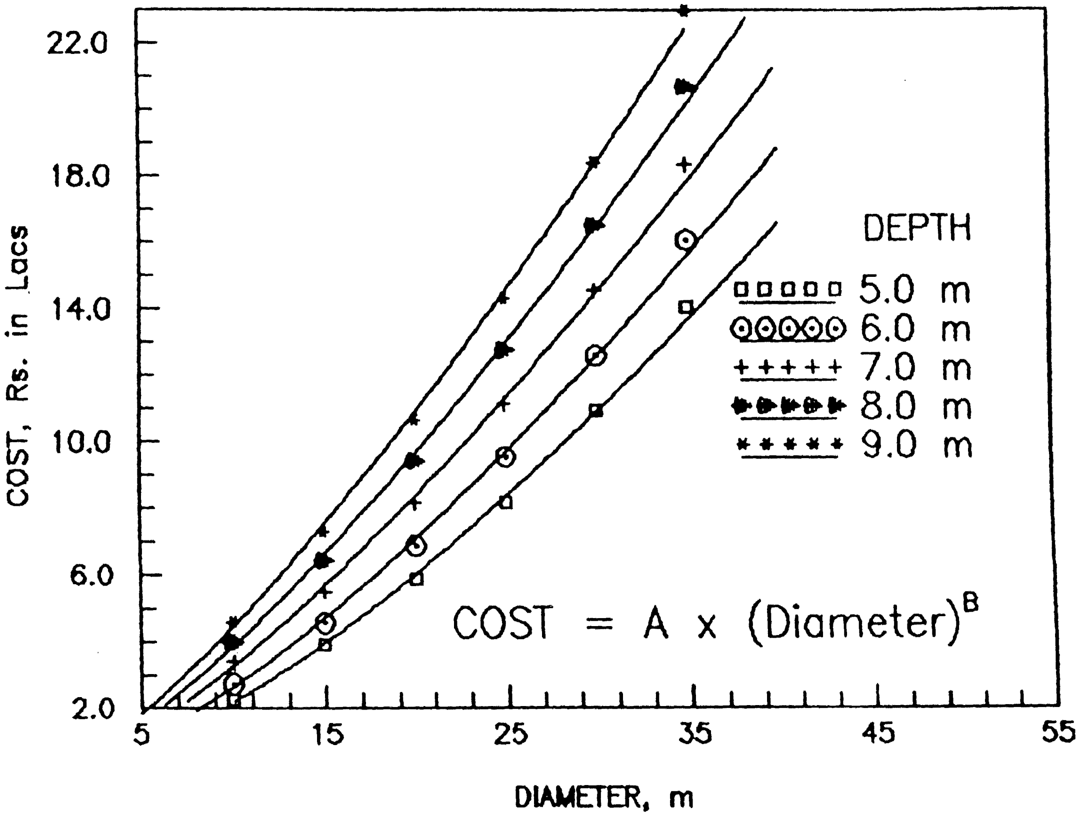



Fig. 20. Variation in Cost of Variable Part of Secondary Clarifier with Surface Area



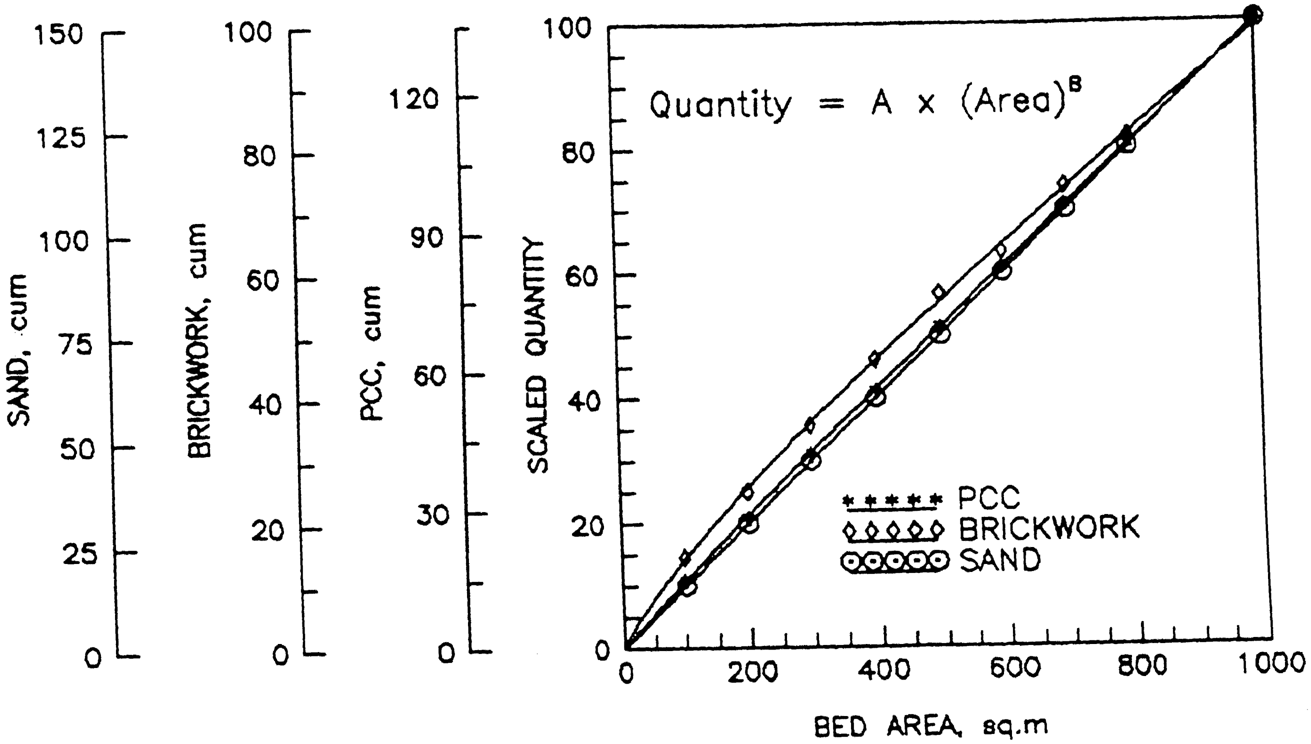

| DIA, m | A | B | R | S | N |
|---|---|---|---|---|---|
| 10.0 | 0.3086 | 1.2296 | 0.9996 | 0.0310 | 5 |
| 15.0 | 0.6861 | 1.0747 | 0.9987 | 0.0804 | 5 |
| 20.0 | 1.1115 | 1.0274 | 0.9990 | 0.0990 | 5 |
| 25.0 | 1.7157 | 0.9651 | 0.9996 | 0.0850 | 5 |
| 30.0 | 2.5777 | 0.8933 | 0.9994 | 0.1269 | 5 |
| 35.0 | 3.6400 | 0.8357 | 0.9992 | 0.1671 | 5 |

Fig. 21. Variation in Cost of Digester with Depth




| DEPTH, m | A | B | R | S | N |
|---|---|---|---|---|---|
| 5.0 | 0.0760 | 1.4600 | 0.9940 | 0.2588 | 6 |
| 6.0 | 0.1024 | 1.4142 | 0.9992 | 0.2821 | 6 |
| 7.0 | 0.1457 | 1.3524 | 0.9992 | 0.3138 | 6 |
| 8.0 | 0.1871 | 1.3165 | 0.9993 | 0.3247 | 6 |
| 9.0 | 0.2282 | 1.2904 | 0.9994 | 0.3318 | 6 |

Fig. 22. Variation in Cost of Digester with Diameter




| ITEM, unit | SCALE* | A | B | R | S | N |
|---|---|---|---|---|---|---|
| PCC, cum | 134.78 | 0.3663 | 0.8171 | 0.9989 | 17.5500 | 10 |
| B/W, cum | 100.90 | 0.3053 | 0.8369 | 0.9996 | 1.1523 | 10 |
| PL, sq.m | - | 0.1000 | 1.0000 | 1.0000 | 0.0000 | 10 |
| Sand, cum | 150.00 | 0.1500 | 1.0000 | 1.0000 | 0.0000 | 10 |
| Gravel, cum | - | 0.2500 | 1.0000 | 1.0000 | 0.0000 | 10 |

* Equivalent to 100; B/W = Brickwork; PL = Plastering

Fig. 23. Variation in Civil Works Quantities with Surface Area for Sludge Drying Beds

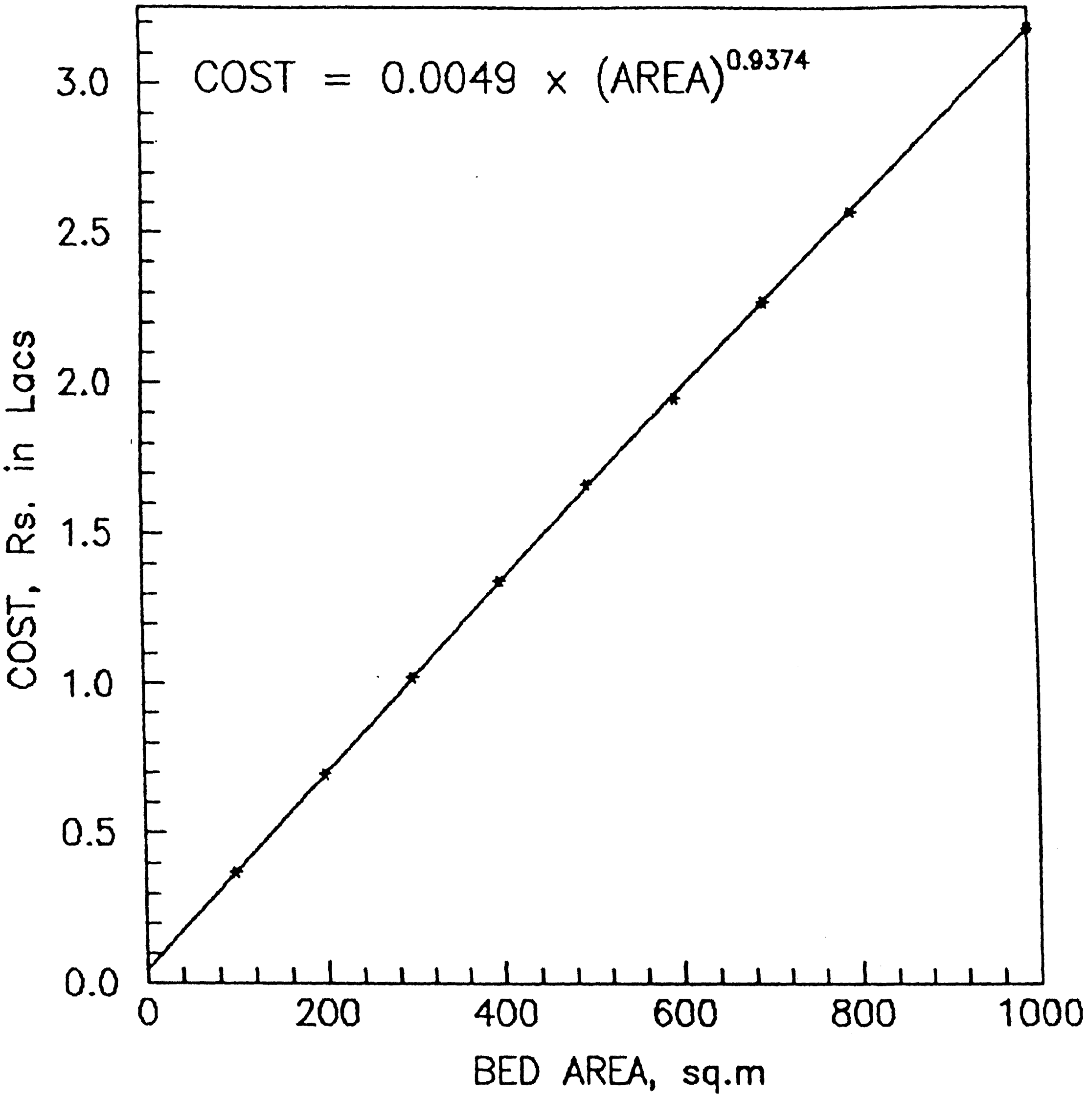
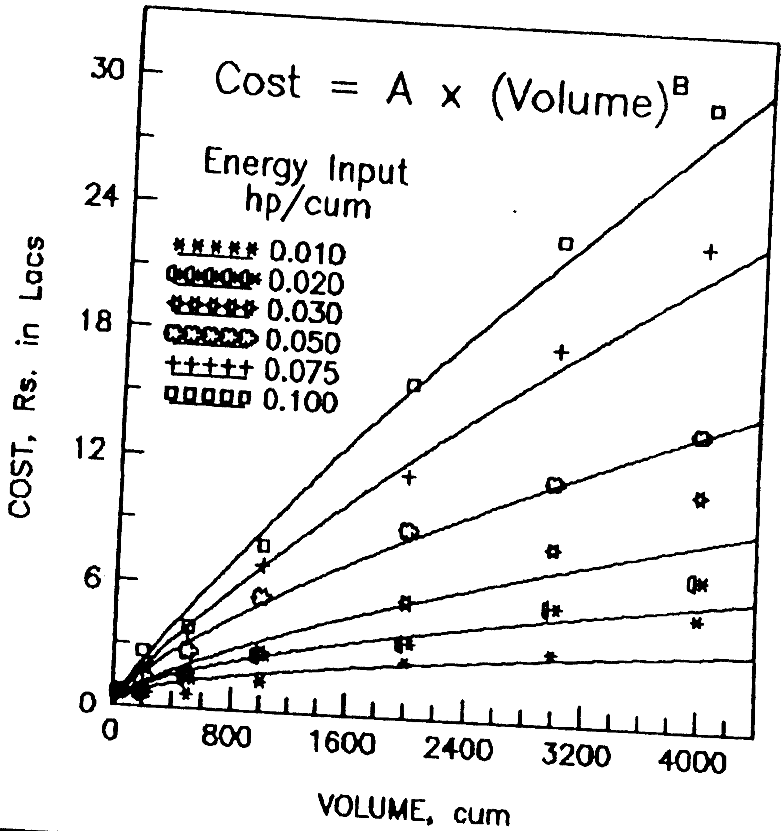
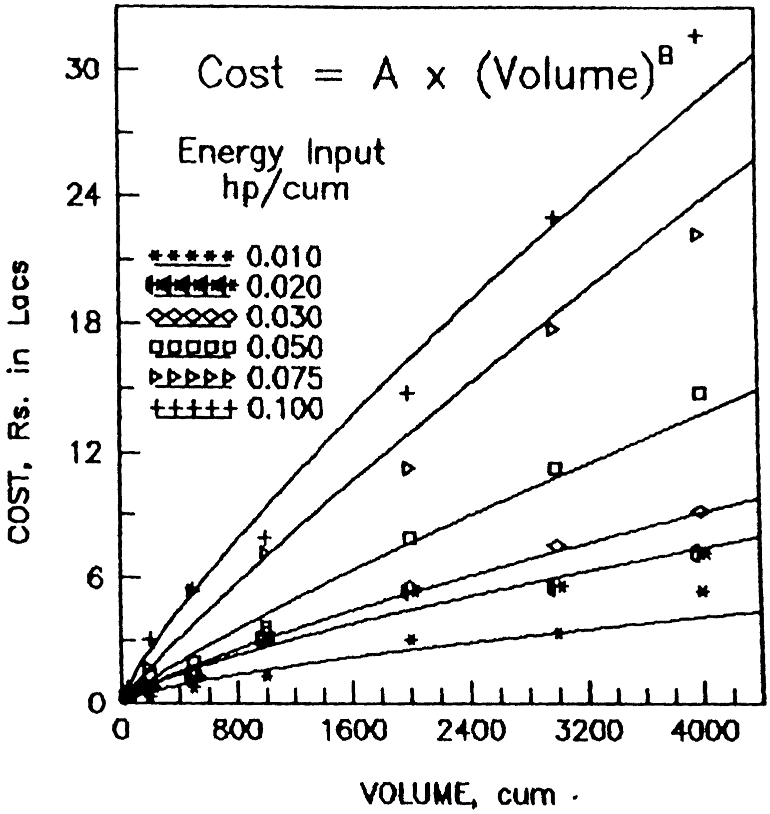



Fig. 24. Variation in Cost of Sludge Drying Beds with Area




| HP/Cum | A | B | R | S | N |
|---|---|---|---|---|---|
| 0.010 | 0.0150 | 0.6770 | 0.9787 | 0.6400 | 7 |
| 0.020 | 0.0180 | 0.7250 | 0.9855 | 0.5100 | 7 |
| 0.030 | 0.0140 | 0.8000 | 0.9977 | 0.8500 | 7 |
| 0.050 | 0.0130 | 0.8430 | 0.9977 | 0.4700 | 7 |
| 0.075 | 0.0160 | 0.8820 | 0.9964 | 1.2550 | 7 |
| 0.100 | 0.0350 | 0.8070 | 0.9928 | 1.6900 | 7 |

Fig. 25. Variation in Cost of Mechanical Equipment with Volume for Square Tank




| HP/Cum | A | B | R | S | N |
|---|---|---|---|---|---|
| 0.010 | 0.0620 | 0.4880 | 0.9630 | 0.7200 | 7 |
| 0.020 | 0.0480 | 0.5810 | 0.9880 | 1.0100 | 7 |
| 0.030 | 0.0280 | 0.6930 | 0.9832 | 1.1000 | 7 |
| 0.050 | 0.0370 | 0.7160 | 0.9985 | 0.9000 | 7 |
| 0.075 | 0.0250 | 0.8120 | 0.9978 | 0.9000 | 7 |
| 0.100 | 0.0250 | 0.8450 | 0.9980 | 0.9900 | 7 |

Fig. 26. Variation in Cost of Mechanical Equipment with Volume for Rectangular Tank

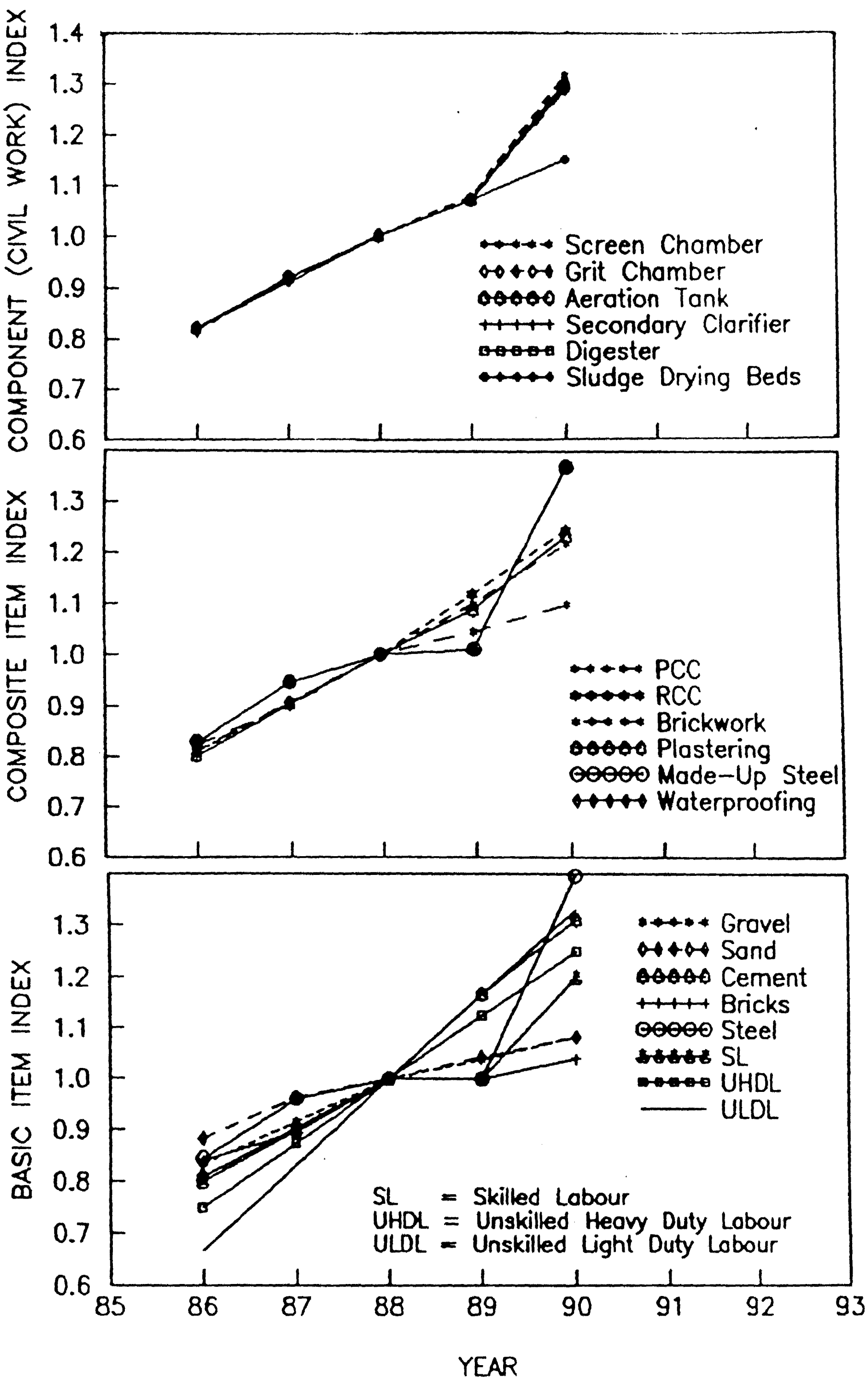



Fig. 28. Index Variation at Three Levels

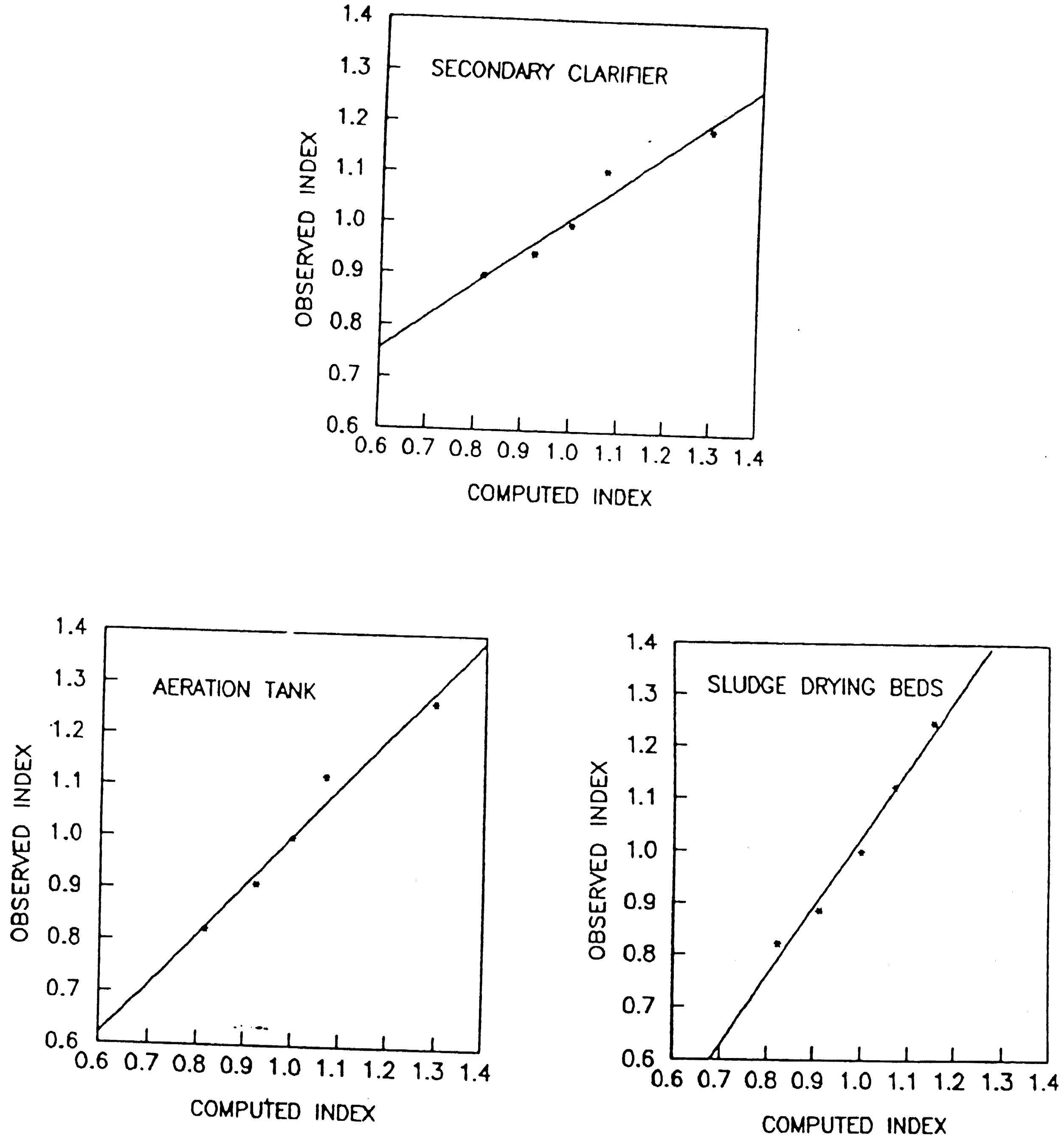



Fig. 29. Comparison of Observed and Computed Unit Operation Component (Civil Works) Index for Unit Operations

# 7. SUMMARY

Predesign estimates of water and wastewater treatment plant costs are necessary for budgetary provisions as well as selection of effective and economical treatment chain. This thesis critically examines the techniques available for rapid estimation of treatment plant costs and suggests a methodology based on part to whole approach. A conceptual model is presented for visualising breakup of treatment plant costs. The overall cost is divided into three types of costs, namely capital, O & M and end user costs. The first two cost types are further divided into costs contributed by several subsystems (units) at various levels in a branched structure with the lowest level of subsystems (units) as basic items (parts). A mathematical formulation based on the conceptual model is derived to obtain capital and O & M costs of the overall plant. The overall cost is considered as sum of the costs of subsystems of various levels involved in a treatment plant. The cost of any level of subsystem is assumed to consist of the cost of subsystems of next lower level and the cost incurred in linking these in an orderly manner. Based on this unit operation cost data which in turn require quantities of various items were synthesised using principles and practices followed by engineers in quantity survey and cost estimations. These data are then utilized in developing quantity and cost curve(s)/function(s) for various unit operations. Six unit operations, namely screen chamber, grit chamber, aeration tank for activated sludge process, secondary clarifier, anaerobic digestor and sludge drying beds were chosen to develope these curve(s)/ function(s). Emphasis is given on civil works cost, though very limited efforts are also made to incorporate mechanical equipment cost for aeration tank and secondary clarifier. Nonlinear regression analysis is employed to obtain best fit curve(s)/ function(s) in terms of the identified capacity parameter(s) of a unit operation for quantities of items involved and the cost.

In order to ensure universal adoptability and continued usability of the results obtained from cost curve(s)/function(s),

application of indices at various levels which appropriately reflect the variation in economic factors over a time and geographic scale from reference conditions is suggested. These indices are formulated in such a way that they reflect the changes in the unit costs (rates) of subsystems/units (basic items) on the changes in the unit costs of higher level subsystems such as composite items, components, unit operation, etc.

Very limited efforts are made to validate the technique suggested for rapid estimation of treatment plant costs. Only the validity of unit operation component (civil works) cost indices is checked through comparison of computed and observed indices for three unit operations for which information could be obtained. The computed indices for these units are in good agreement with the observed indices.

While going through the exercise of formulation, collection and analysis of data, compilation of results and preparation of the manuscript, several questions/doubts/points were raised which could not be given due consideration in the scope of the present work. A few of these are mentioned here to serve as guidelines for the future research as a logical continuation of the research presented in this thesis.

1. The curve(s)/function(s) developed for quantities and costs of civil works are based on the structural dimensions of the units for a typical site conditions assumed. Thus these curve(s)/function(s) should be developed for various site conditions.

2. Only six unit operations are considered in the present work. The work should be extended to all commonly used unit operations.

3. Though the approach presented is general, emphasis is given on civil works costs. Hence, work should be carried out for other costs such as mechanical equipment, electrical works, piping, etc.

4. In the formulation it is stated that some fraction of cost of sum of the costs of various subsystems is involved in linking these in an orderly manner to get the next higher level subsystems. Efforts should be made to come up with some logic to arrive at the values of these fractions.

The results of the present study as well as from further studies on aforementioned lines, however, would not be acceptable for field application unless it is demonstrated through comparison of the actual cost of the plant already commissioned and that computed using the suggested technique. The importance of data collected/synthesised from a systematic programme of field investigation is self evident.

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